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THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XXI.—*On the Use of the Stereographic Projection for Geographical Maps and Sailing Charts;* by S. L. PENFIELD.

Introduction.—Maps are generally made by first plotting a system of parallels and meridians, which are then used as guide-lines for locating places, and tracing the outlines of countries, courses of rivers, etc. Numerous methods of plotting parallels and meridians have been employed, some based upon exact mathematical principles of projection, others upon geometrical methods of development, while others are wholly arbitrary schemes and have no mathematical justification, hence, as might be expected, the results of map drawing are quite various, and often far from satisfactory. It is of course impossible to represent the curved, bulging surface of a sphere upon a plane without distortion of some kind, and this may become very pronounced if the extent of country covered by the map is large, but still there is no just reason for the marked variations and discrepancies which may be observed on maps in general use at the present time.

It is not the object of the present communication to enter into a detailed discussion of the general subject of map projection. On the other hand, an endeavor will be made to set forth certain advantages which would result from using a well known method of projection, known as the *Stereographic.* Attention will also be called to certain misconceptions which seem to exist concerning this most admirable method of projection.

Doubtless all will agree that maps should fulfil three important requirements: First, the shapes of land and water

areas on maps should appear as nearly as possible the same as on a globe. This requires that the spaces included between the projected parallels and meridians should be nearly the same, proportionately, as on a sphere, and that angles are preserved, or but slightly distorted. Second, if a map is published with a scale of miles, it should be possible by means of it to measure distances between places with reasonable accuracy. This is a most important consideration, for most persons must rely wholly upon maps for the estimation of distances. The determination of distances by calculation, requiring a knowledge of spherical trigonometry and the use of formulas and tables of logarithms, is far too laborious to be generally applicable. Lastly, the tracks of great circles, the directions along which the shortest distances between places on a sphere are measured, should be found easily on maps, and angles should be preserved so that bearings may be taken. This last consideration is a most important factor in navigation. In the pages which follow it will be shown to what extent maps based upon the stereographic projection fulfil the aforementioned requirements.

In a previous communication entitled "*The Stereographic Projection and its Possibilities, from a Graphical Standpoint*,"* the principles of the projection have been set forth by the present writer, and special scales and protractors were described by means of which it was possible not only to plot all kinds of problems in spherical trigonometry with facility and accuracy, but, also, to measure the parts of triangles thus plotted. A considerable portion of the paper was devoted to a discussion of the possibilities of applying the principles of the stereographic projection to *map making*, and the present article may be considered as an elaboration of the ideas there presented. It is not considered necessary to discuss again the principles of the stereographic projection, but for the benefit of those who may not be familiar with the subject a brief statement of some of its essential features may not be out of place.

Essential Features of the Stereographic Projection.—Stereographic maps are based upon a very simple principle of projection. The point from which the lines of projection emanate, which may be regarded as the *point of vision*, is at the surface of the sphere, and it may be imagined that one is looking as it were through a hollow earth at the surface opposite. The plane upon which the projection or map is made must be at right angles to the diameter of the sphere which passes through the point of vision. It is generally convenient

*This Journal (4), xi, pp. 1–24 and 115–144, 1901.

to consider the plane of the projection either as passing through the center of a sphere, figure 1, or as tangent to it, figure 2, but, provided its direction is not changed, the position of the plane may be altered without in any way affecting the character of the projection; the size becomes greater as the plane is shifted to a position farther from the center.

Figure 1 is a photographic reproduction of a model constructed by the writer which needs but little explanation.

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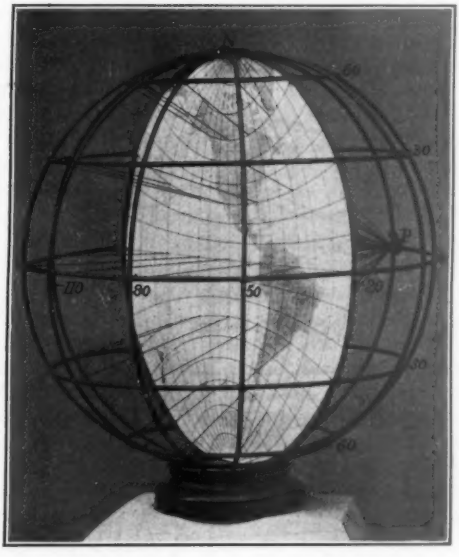

Model for illustrating the principle upon which the stereographic projection is based.

The original skeleton sphere, made of wire, is eighteen inches in diameter, and the map of the Western Hemisphere, drawn on cardboard, is inserted at the center. Following the custom of geographers, the meridian bounding the map is numbered 20° W. (160° E.), and the plane upon which the map is drawn is at right angles to a diameter running from the intersection of the 110th meridian and the equator to the point *P*. Lines of projection are indicated by threads running from *P* to the intersections of the meridians with the parallels and equator.

Figure 2 is a diagram plotted in clinographic projection, the same as is used in drawing crystal figures. The original draw-

ing was plotted with much care on a large scale, hence the construction of the figure may be regarded as reasonably exact. It represents the lines of projection extending from P to a plane tangent to the sphere at a point antipodal to P, which, in this case, is the intersection of the equator with the

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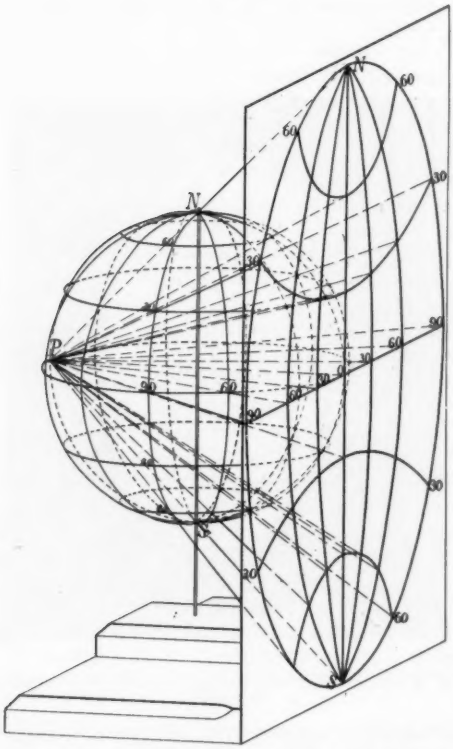

Diagram for illustrating the principle of the stereographic projection upon a tangent plane.

meridian numbered 0°. A bright light held close to a skeleton sphere in a position corresponding to P, would cast a shadow of the parallels and meridians upon a tangent plane corresponding exactly with the lines shown in figure 2. If figure 2 is viewed with one eye through a short cylinder made by rolling up a sheet of paper, or through, as it were, a tube formed by doubling up the hand, the lines of the drawing will

stand out with rather surprising stereoscopic effect, making the figure appear much more real. It is believed that a careful consideration of either of the figures here presented will serve to convey a clear idea of the principles upon which the stereographic projection is based.

Three kinds of stereographic maps come under consideration: (1) projection upon the plane of the equator, when the point of vision is at one of the poles; (2) projection upon the plane of a meridian, when the point of vision is at some point on the equator; while (3) if the point of vision is at any position other than the ones mentioned, the map may be considered as made on a plane tangent to the sphere at the antipodal point: such a map is said to be made upon the plane of the horizon, and the latitude and longitude of the point of tangency should be given.

Important features of the projection are as follows: As shown by figures 1 and 2, when a circle of a sphere passes through the point of vision it is projected as a straight line on the map, while all other circles are projected as *circles*,* which appear generally as *portions of circular arcs* on maps. This is a most important feature, for no other lines can be more accurately constructed than circles, and by making use of a few simple mathematical principles it is possible to project a system of parallels and meridians, *the very foundation of a map*, with almost absolute accuracy. Angles are preserved, and the stereographic is the only true projection which possesses this important feature, although by methods of development maps are produced (the so-called Mercator's projection, for example) where angles are preserved. A given distance is represented by varying lengths on different parts of a stereographic map, but the distortion of distances is of a nature deserving most careful consideration. Starting from the center of a hemisphere, the distances from degree to degree become gradually greater as the periphery is neared; the rate of increase, however, is very slight at first. Within a radius of 90° from the center the maximum variation is such that the distance from the eighty-ninth to the ninetieth degree fails just a little of being twice as great as from the center to the first degree. This important subject of distortion will be considered more fully in a later paragraph. In spite of distortion, however, distances may be measured with facility and accuracy on stereographic maps, provided use is made of specially devised *Stereographic Protractors* previously described by the writer.† These may be of various forms; one of which is represented, much reduced, by figure 3, and the use of this and other forms,

* This Journal (4), xi, pp. 8–13, 1901.
† Loc. cit., pp. 17–23.

as applied to map measurement, will be illustrated by numerous figures later. The protractor shown in figure 3 is nothing else than a series of great circles and small circles, corresponding to the meridians and parallels of half of a hemisphere, stereographically projected upon the plane of a meridian. The lines may be printed or engraved on some transparent material, such for example as celluloid, which is almost ideal for the purpose.

When the stereographic protractors were described by the present writer he was not aware that similar devices had ever been made use of before, and he is indebted to Mr. G. W. Littlehales of the Hydrographic Office at Washington for calling

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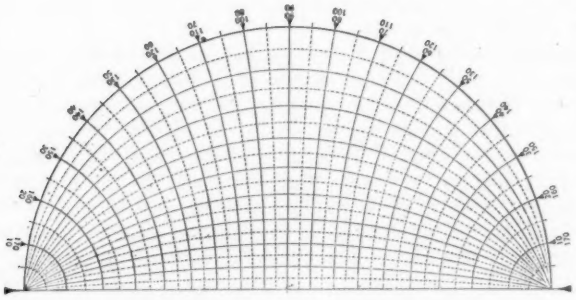

Stereographic Protractor with great circles and small circles; five degree graduation.

his attention to the fact that for purposes of navigation Chauvenet had previously suggested the use of a protractor based upon the same principles. Chauvenet's discovery seems to be known to but few, and the only information which the writer has been able to find concerning it is contained in a letter from Mr. Littlehales, as follows: "The original plates of the Great Circle Protractor now in the possession of the Hydrographic Office show by the inscriptions engraved upon them that the Protractor was originally known as Professor William Chauvenet's Great Circle Protractor. The plates appear to have been purchased by the Bureau of Navigation from Professor Chauvenet about the year 1867 and used for many years thereafter by the Hydrographic Office for the issue of prints. I am unable to discover when the method was originally devised by Professor Chauvenet."

Chauvenet seems never to have developed the full possibilities of his protractor, though they must have been evident to him; moreover, at the time his protractor was first described it could scarcely have been regarded as a wholly practical and

serviceable working instrument, for in order to bring it to anything like perfection there was needed some cheap and strong transparent material, such as celluloid, on which to print or engrave it.

Historical.—Before proceeding to a discussion of maps it will be well to consider briefly the history of the stereographic projection. It is said to have been invented by the astronomer Hipparchus, who lived at Rhodes about 150 B. C. It is also said that Ptolemy, sometimes called the father of geography, who lived at Alexandria about 150 A. D., employed the projection in making maps of the then known world. Almost the best description of the projection which the writer has seen appears in a publication entitled "A New and Complete Dictionary of Arts and Sciences, Illustrated with Copper Plates engraved by Mr. Jefferys, Geographer to his Majesty. By a Society of Gentlemen." Printed in London in 1764. It may be owing to Mr. Jefferys' connection with the editorial staff that the article on maps is rather more elaborate than one finds generally in such publications. At all events, the principles of the projection and methods of making maps are admirably set forth, and figures are introduced of the northern and southern hemispheres, and of a hemisphere on the plane of the horizon of London. In discussing the maps, attention is called to the distortion which they exhibit, and the statement is made that "the course and distance between places is neither with ease or exactness found in this projection." The Encyclopædia Britannica in its article on geography gives an admirable account of the stereographic projection, but closes the discussion somewhat abruptly as follows: "Notwithstanding the facility of construction, the stereographic projection is not much used in map making." This, as far as the writer has been able to discover, is a correct statement. Prior to one hundred years ago the projection was generally used, while of modern publications the writer knows only of a few school geographies in which the hemispheres are in stereographic projection, while for maps of limited areas it is seldom if ever used.

There seems to be a want of exact information concerning maps by those who teach geography, as well as lack of appreciation of those features which count for so much in maps, namely, facility of construction, combined with accuracy. In several treatises on Map Projection of quite recent date which have been examined, the stereographic projection is passed over hurriedly, as though it had no special value for map making, while it will be one of the chief objects of this communication to demonstrate that, all things considered, it is by far the best of all projections for geographical maps.

As an illustration of misconception concerning the projection, attention may be called to some statements and illustrations observed in a Physical Geography intended, as stated on the title page, "for the use of Schools, Academies and Colleges." In the chapter on *Mathematical Geography* the following statement concerning maps was observed: "The pro-

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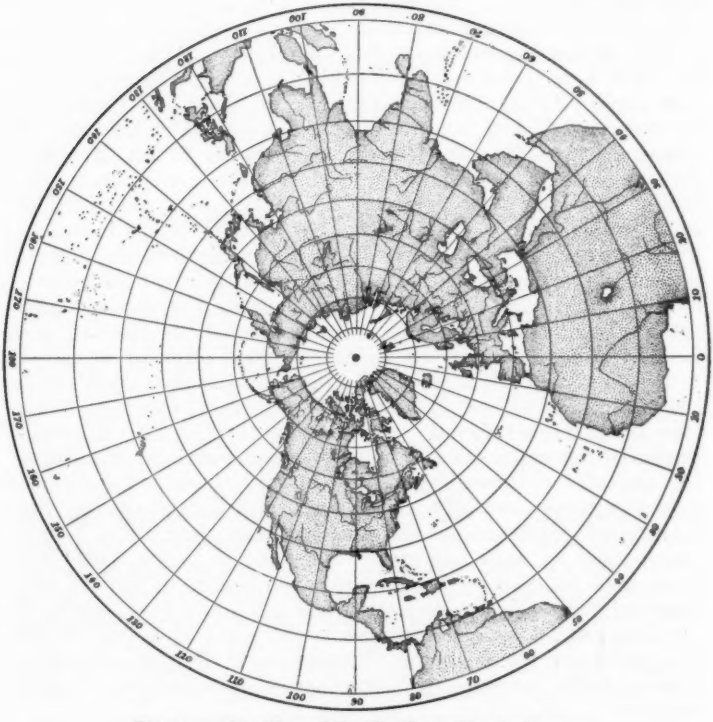

Stereographic Map of the Northern Hemisphere.

jections in most common use are Mercator's, the orthographic, the stereographic and the conical. Of these the stereographic is best adapted to ordinary geographical maps and Mercator's to physical maps." Then, after giving correctly the principles upon which the stereographic projection is based, it is stated that "the two stereographic projections in most common use are the *Equatorial* and the *Polar*," while the accompanying illustrations are not stereographic, but the so-called *globular projections* of the hemispheres, which will be referred to later.

Projection upon the plane of the Equator.—This is the simplest kind of stereographic projection. The meridians appear as straight lines, figure 4, and the parallels as concentric circles. The lengths of the radii for describing the parallels may be determined by projection,* but are best taken from tables, as described in a note at the close of this article. Attention may be called to the fact that, in spite of distortion, the shapes of the countries shown on the map are admirably preserved, as may be seen by comparing the map with a globe.

In order that such a subject as Mathematical Geography may be in every way practical it must be made exceedingly simple. In the writer's earlier communication, already referred to, Plate II represented an engine divided projection upon the plane of the equator; that is, a system of meridians and parallels projected with practically *absolute accuracy*. In connection with such a plate it is now proposed to use an engine

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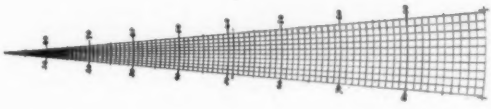

divided scale, figure 5, printed on tracing paper, which may be placed over a projection of corresponding size, between any two meridians. To locate a place of given latitude or longitude, for example New York, 40° 43′ N., 74° W., it is only necessary to adjust the scale between the appropriate meridians on the map, find the desired location, and then puncture with a needle point through the scale to the plate below. With an engraved plate one foot in diameter and an accompanying scale, figure 5, it would be crude plotting if places were not located within a quarter of a degree of their true geographical position on the plate, and, with care, errors of over five miles ought not to occur.

In figure 6 several places are shown as they were located on a 14^{cm} (5½ inch) diameter, engine divided plate, from the following data:

Greenwich	00°	00′		51°	23′ N.
San Francisco	122	25	W.,	37	47 N.
Honolulu	158	00	W.,	21	30 N.
Northern Luzon	121	00	E.,	19	00 N.
M	105	00	E.,	52	30 N.

* The methods of making the projection have been given by the writer in an earlier communication. Loc. cit.

The great circles shown, such as from Northern Luzon, Philippine Islands, to San Francisco, Luzon to Honolulu, etc., were drawn on the plate. The illustration also shows a celluloid protractor, figure 3, over a portion of the plate in position suitable for measuring the distance from Luzon to San Francisco. Starting from the upper zero of the protractor, Luzon

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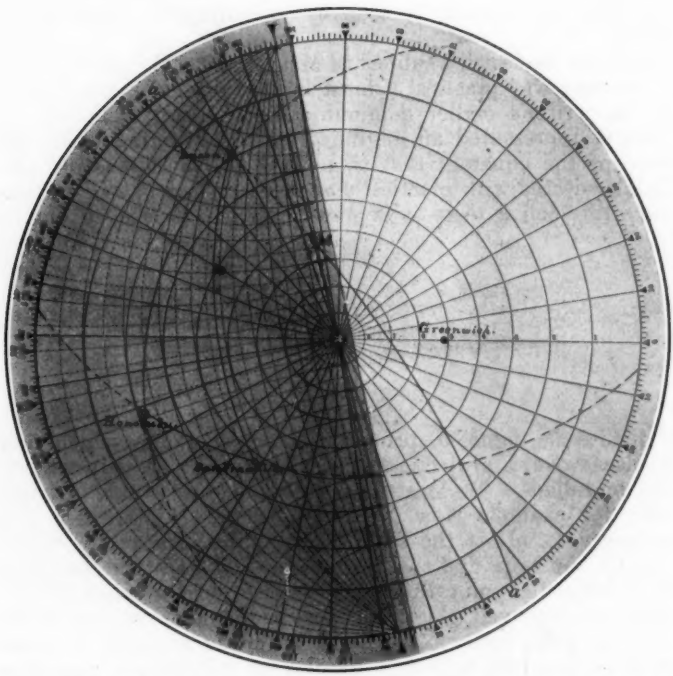


Stereographic Protractor adjusted for measuring from Luzon to San Francisco along the arc of a great circle. See Note.

is about 26° and San Francisco about 124° from the periphery, and the difference, 98°, is the distance. Using a protractor with finer graduation, such as shown in figure 12, the distance was

NOTE.—Figure 6 and other similar half-tone illustrations have been made from photographs of drawings over which stereographic scales, printed on transparent celluloid, have been laid. The celluloid being of a yellowish tone of color, those portions of the drawings covered by the protractors appear darker in the photographs and half-tones, and thus may be easily recognized. The lines on the original celluloid protractors are very fine, and appear still finer in the reduced half-tones, but it is believed that they are sufficiently distinct for purpose of illustration.

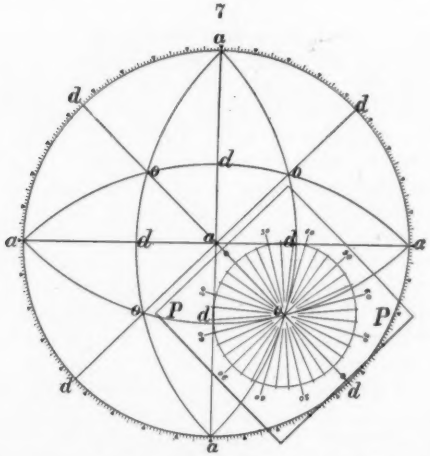
found to be 97° 50′, while by calculation it is 97° 45′. To measure from Luzon to Honolulu, and from Honolulu to San Francisco, along the great circles drawn on the plate, it would be necessary to turn the protractor about its center until its 0° and 180° points corresponded with the intersections of the equator with the two great circles shown in the figure. The distances, as measured with the protractor shown in figure 12, were 75° 5′ and 34° 30′, as against 75° 7′ and 34° 40′ by calculation.

Even when it is desired to measure from the northern to some point in the southern hemisphere, it may be accomplished easily. Take, for example, from Luzon to the western entrance of the Strait of Magellan: Referring to an atlas sheet of South America, the entrance to the Strait is found to be 75° W., 52° 30′ S., hence the antipodal point, *M*, figure 6, is located in the northern hemisphere on the continuation of the seventy-fifth meridian (105° E.) at 52° 30′ N. Measurement is then made from Luzon to *a*, on the equator, and, taking up the measurement from the opposite point, from *a′* to *M*, along that portion of the great circle indicated by a full line. This distance measured with a protractor was found to be 144° 10′ as against 144° 15′ by calculation. Another way would be to measure from Luzon to *M*, along that portion of the great circle which is dashed, when the supplement value gives the desired distance from Luzon to the Strait. The track of the great circle indicated by the diagram could not be sailed, as it runs through Australia and other islands. Another and simpler method of measuring from one hemisphere to another will be indicated in a later paragraph.

In addition to facility of construction, projections on the plane of the equator are especially adapted to ready measurement of angles, since a meridian through any point, which gives a true north and south direction, is a straight line. Methods of measuring spherical angles have already been described by the writer,* and figure 7 is an illustration, taken from crystallography, of a still simpler method of making such measurements. It is recommended to use a special protractor *PP*, having the lines of graduation continued to near the center, and which could easily be engraved by means of a dividing engine. From *a*, figure 7, to the nearest point marked *d* is 45°, and three great circles running from *a* to *d* intersect at the points lettered *o*; the angles made by the meeting of the great circles at *o* being exactly 60°. To measure an angle, the protractor, printed on transparent celluloid, is centered as at *o*, figure 7, its 0°–0° line is made to coincide

* Loc. cit., pp. 18 and 19.

with a diameter, and it may then be told by inspection what line of the protractor is tangent to the great circle under consideration. In the example cited it is evident that the 60° lines of the protractor are tangent to the great circle arcs passing through *o*. With such a protractor it is probable that angles could be measured to within a quarter of a degree or closer, depending upon the size of the projection.



Method of measuring spherical angles at the point *o* by means of a transparent protractor, *PP*.

Projection upon the plane of a Meridian.—Figures 8 and 9 represent the Western and Eastern Hemispheres in stereographic projection on the meridian 20° W., 160° E., from Greenwich. The construction of the meridians and parallels is a very simple matter. A circle of any desired size and two diameters at right angles to one another are first drawn. The points of intersection of the meridians with the equator and of the parallels with the central meridian are next determined, best from a table, while the radii of the several meridians and parallels are likewise taken from tables described in a note, at the close of this article. Attention may be called to the following interesting relations which may at times be useful. The center points about which the meridians 10°, 20°, etc., from the periphery are described are the stereographically projected 20°, 40°, etc., points on the equator, measured from the center. The lengths of the radii for describing the parallels 10°, 20°, etc., from the poles are the distances from the center of the map to the stereographically projected 20°, 40°, etc.,

points. Notwithstanding these relations and the facility with which all necessary intersections may be determined by methods of projection, as generally recommended in treatises on the stereographic projection, in practice it will be found that measurements derived from tables, as suggested, will make the work not only much easier, but, what is of far greater import-

8

Stereographic Map of the Western Hemisphere.

ance, more accurate. By making use of the graphical methods, described by the writer in a previous communication, the network of meridians and parallels may be constructed in a remarkably short space of time; in fact, this projection, though seemingly more complicated, is scarcely more so than the one made on the plane of the equator, figure 4.

Attention is invited to a comparison between the shapes of the continents as they appear on the maps, figures 8 and 9, and on a globe, when the latter is turned so as to show the

shapes of the several land areas to best advantage: also to a comparison between the shapes of the North American Continent on the two kinds of maps, figures 8 and 4. It will thus be found that the shapes of the continents have not been materially altered by mapping in stereographic projection. One effect of distortion may be seen by observing, for example,

9

Stereographic Map of the Eastern Hemisphere.

Greenland in two positions, figures 8 and 4. The shape is well shown on either map, but it appears considerably larger near the periphery than when near the center. Variation in size, however, is not a matter of so great importance, since on all maps the distances between the parallels, as measured along a meridian, give a measure of length, and in either position it may be seen that Greenland is about 22° (1320 geographical miles) long, with a width at the 70th parallel of about 10° (600 miles).

Ability to follow the tracks of great circles and to make all kinds of measurements on maps is of course a most important feature, and figure 10 gives the partial solution of the problem of navigating a ship by great circle sailing from the Hawaiian Islands, *H*, to New York by way of the Strait of Magellan, *M*. The figure represents a map (the original was 14^{cm} diameter) with a stereographic protractor over it, so adjusted as to

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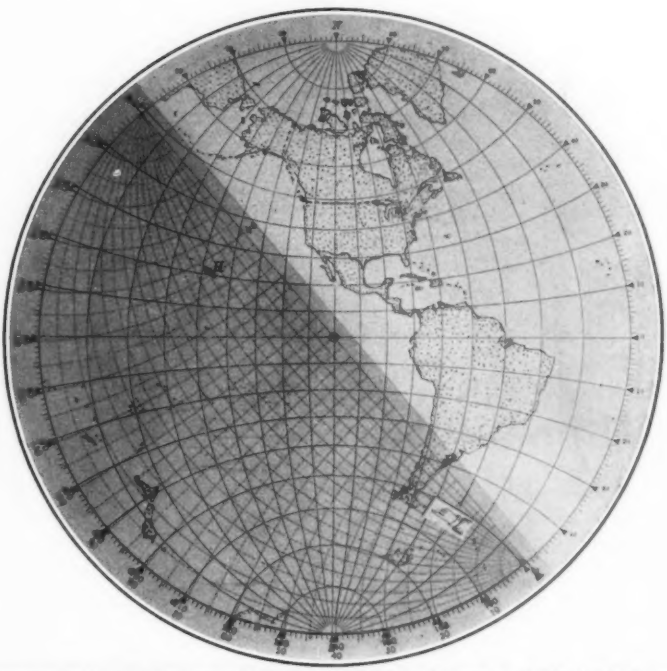

Stereographic Protractor adjusted for finding the great circle track from Honolulu, *H*, to the Strait of Magellan, *M*, and measuring the distance.

bring *H* and *M* on the same great circle, indicated by the pointer. The distance is determined by the small circles; thus, starting from the top, or zero of the protractor, *H* is at about 43°, and *M* at 146° from the zero-point, and the difference, 103°, is the distance. The great circle track from which bearings may be taken is the circular arc *HM*. After traversing the Strait, portions of three great circles may be followed, shown in figure 11; thus, from *M* to *a*, from *a* to *b*,

and from *b* to New York. Figure 11 illustrates another kind of stereographic protractor, designated by the writer in an earlier paper* as No. IV, and its use in finding any great circle track, as, for example, that from *b* to New York, is almost too simple to need explanation. One has merely to center the protractor and turn it until some great circle is found which passes through the desired points or close to

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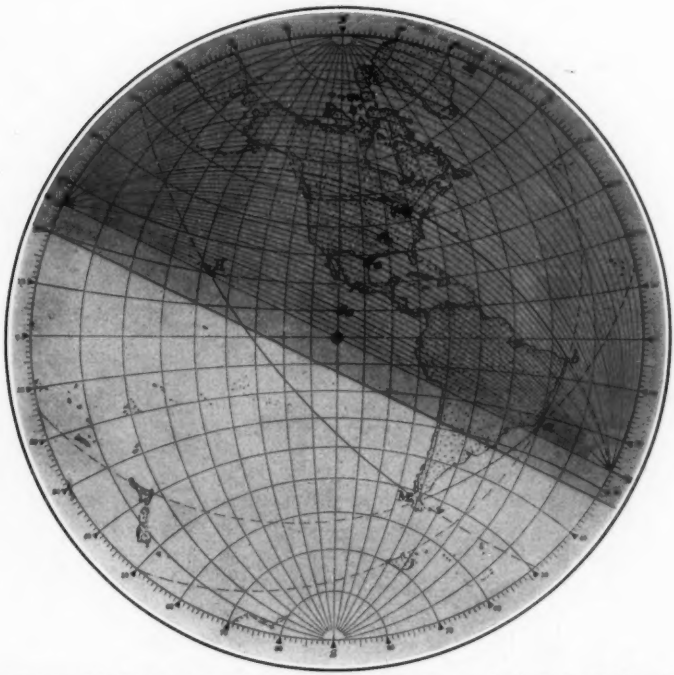


Stereographic Protractor adjusted for finding the great circle track from *b* to New York. Other great circles, *H* to *M*, *M* to *a* and *a* to *b*, have been drawn on the map. Great circles only are printed on the protractor.

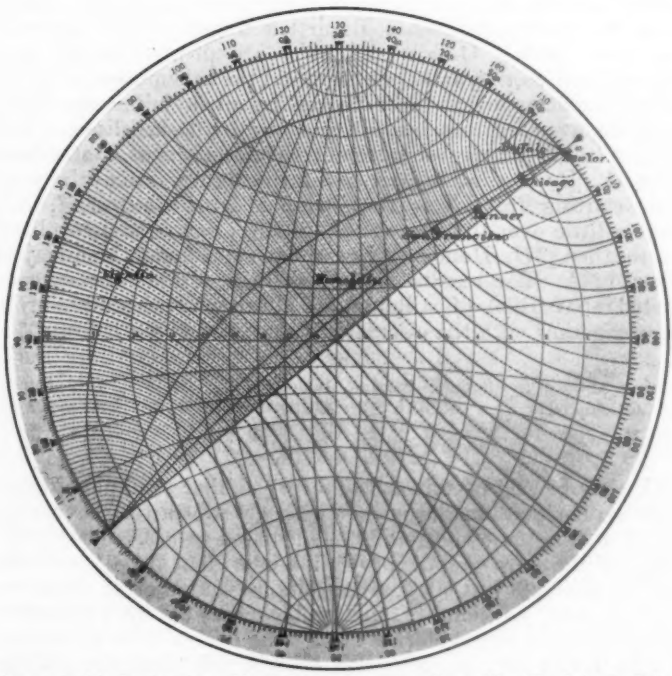
them. In order to measure the distances a protractor like the one shown in figure 12 may be employed, and by using it the distances to be sailed in going from Honolulu to New York were found to be as follows: From *H* to *M* 103°, through the Strait 5½°, from the Strait to *a* 37°, from *a* to *b* 17°, and from *b* to New York 58½°, a total of 221°, or 13,260 geographical

* Loc. cit., pp. 21 and 22.

miles. It takes but a few minutes to make such a series of measurements, and the results are accurate. Moreover the method is so simple that any one could easily be taught to use the protractors and thus learn an important lesson in mathematical geography.

Figure 12 represents the method of solving the following problem: To find the distances from New York to Buffalo,

12



Stereographic Protractor adjusted for measuring from New York to Buffalo, Chicago, Denver, San Francisco and Manila. Small circles only are printed on the protractor.

Chicago, Denver, San Francisco, Honolulu and Manila, the latitudes and longitudes of the places being given. The places were located on a 14^{cm} diameter, engine divided plate from the following data:

New York.	Buffalo.	Chicago.	Denver.	San Francisco.	Honolulu.	Manila.
Lat. 40° 43′ N.	42° 53′	41° 50′	39° 45′	37° 47′	21° 20′	14° 36′
Long. 74 00 W.	78 55	87 34	105 0	122 25	157 55	239 8
Long. of New York	74 00	74 00	74 00	74 00	74 00	74 00
Long. W. from New York	4 55	13 34	31 00	48 25	83 55	165 8

New York is located on the outer circle, which is taken as its meridian, at 40° 43′ N. The longitudes of the remaining places with reference to New York are obtained by subtracting the longitude of New York from them, as indicated above, and they are then located at their given latitudes. A few great circles have been drawn on the plate, from New York through Denver, Honolulu, Buffalo and Manila, but for the sake of measurement it was not necessary to construct them. After locating the places, a celluloid protractor* was placed over the plate and a photograph taken from which figure 12 has been made. Only small circles are printed on the protractor, and, as they fall close together, the scheme was adopted of representing every tenth degree by a heavy line, the intermediate even degrees by full, and odd by dashed lines. The dots within the circles represent the locations of the several places. By careful inspection of the figure it may be seen that, starting from New York, Buffalo is a little over 4°, Chicago a little over 10°, Denver about 23⅜°, San Francisco a little more than 37°, Honolulu just short of 72° and Manila just over 123°. The results of the readings of the protractor as stated above, and of still another plotting of this same problem, together with the calculated values, are given below:

Distances from New York.	Buffalo.	Chicago.	Denver.	San Francisco.	Honolulu.	Manila.
Calculated	4° 18′	10° 16′	23° 34′	37° 9′	71° 49′	123° 2′
Measured	4 5	10 10	23 40	37 10	71 55	123 5
	4 20	10 5	23 40	37 10	71 45	123 5

It may be said of this and of every similar example cited in this article that measurements with the protractors have been made without knowledge of the calculated values. The superiority of the stereographic projection is evident from the results of the example just cited, where the maximum error from two independent solutions of the problem was but 13′ (15 statute miles) and the average error but a trifle over 5′. It is further to be taken into consideration that in this example a whole hemisphere was projected within a circle of 14^{cm}, 5½ inches, diameter. It is of course evident that by increasing the size still greater accuracy would be attained. To locate places with accuracy on a plate with only ten degree spacing of the parallels and meridians requires some experience. In the example just cited places were located by means of the graphical methods described by the writer in a previous article. To gain an idea of how accurately measurements may be made on an engraved plate, 14^{cm} diameter, using no other guide than the eye in interpolating places between the ten degree spaces,

* Designated by the writer in an earlier paper as No. II. Loc. cit., p. 17.

the problem given above was twice plotted, and measured as shown in figure 12, with the following results:

Distances from New York.	Buffalo.	Chicago.	Denver.	San Francisco.	Honolulu.	Manila.
Calculated	4° 18′	10° 16′	23° 34′	37° 9′	71° 49′	123 2′
Measured	3 50	10 15	23 50	36 45	72 00	123 00
	4 10	9 55	23 40	36 45	71 50	123 00

The maximum error here amounts to 28′, and the average is 12′: Hence an accurate plate and a protractor is all that is needed for quickly solving problems with close approximation to the truth.

To locate places easily and at the same time accurately it is recommended to use, in connection with an engine divided plate as already described, a projection of the parallels and meridians, figure 13, printed on tracing paper. When matched over a plate of corresponding size, any place may be located by puncturing with a needle point through the protractor to the plate below.

Figure 13 is a reproduction by photo-engraving of a stereographic projection 18 inches in diameter, published by Captain C. D. Sigsbee, U. S. N., in an atlas folio entitled "Graphical Methods for Navigators."* Captain Sigsbee's protractor is practically identical with Chauvenet's *Great Circle Protractor* and was perhaps printed from Chauvenet's original plate in possession of the Hydrographic Office. It is circular, and figure 13 represents only half of it, reduced to 14^{cm} diameter to correspond with the engine divided plate described by the present writer. A serious objection to the use of such a protractor when on a small scale, is that the lines are so crowded as to be confusing. This difficulty, however, is to a great extent obviated by using two protractors, one having only great circles, the other only small circles, as shown in figures 11 and 12, respectively.

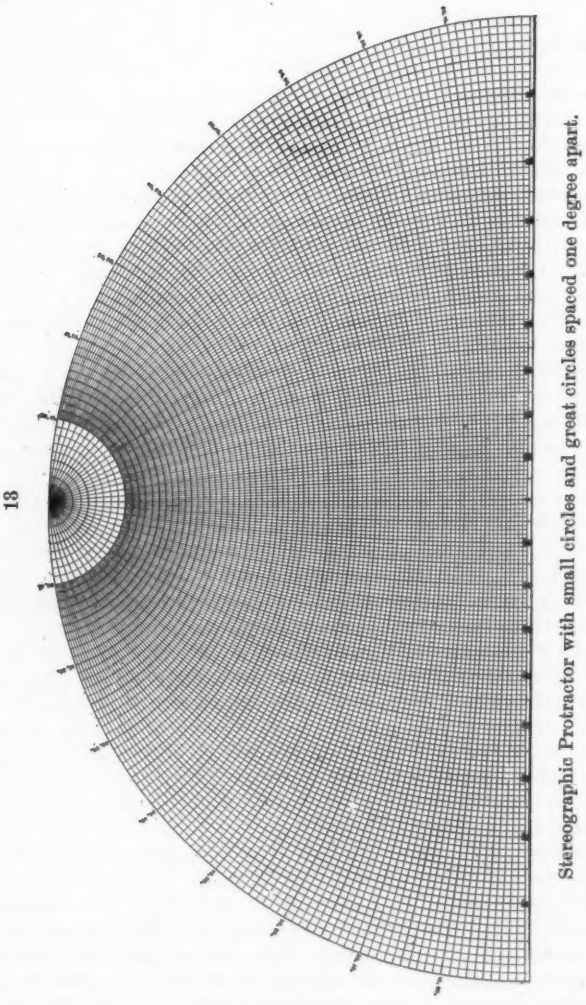
An excellent summary of graphical methods applied to great circle sailing, based upon the stereographic projection, may be found in a publication by Mr. G. W. Littlehales† of the U. S. Hydrographic Office, Washington.

Stereographic Map of the World. Planisphere of the Antipodes.—Figure 14 represents a combination of stereographic projections of the western and eastern hemispheres, which it is believed would make a most useful kind of a map. It is scarcely necessary to state that the northern and southern hemispheres might be combined in a similar manner. The important feature of the map is that any point on one of the

* U. S. Hydrographic Office, Washington, 1896.

† The Development of Great Circle Sailing. Washington: Government Printing Office, 1899, p. 36.

hemispheres covers the antipodal point on the other. In order to accomplish this the poles are reversed, and one of the hemispheres must be like a negative in photography. Thus,



Stereographic Protractor with small circles and great circles spaced one degree apart.

in figure 14, the western hemisphere appears as we are accustomed to seeing it, while the eastern hemisphere may be made to appear right, as in figure 9, page 258, by turning

the page upside down and viewing the figure reflected from a mirror. It is believed that the reversal of one of the hemispheres is a feature that will not prove especially confusing to those well accustomed to maps. The effectiveness of the map would be much enhanced if skillfully engraved on a large scale and printed in two colors, one for each hemisphere, selected so

14

Stereographic Map of the World. Any point on one hemisphere covers the antipodal point on the other.

as to give a pronounced and pleasing effect where overlaps of land surfaces occur. Such a map, issued with a protractor, would be most useful for finding out great circle tracks, and making all kinds of measurements in mathematical geography. Some examples will serve to indicate the uses of the map, which is supposed to be accompanied by a stereographic protractor. The two hemispheres must be kept distinctly apart in thinking of the problems, and will be designated as *W.H.*, western, and *E.H.*, eastern, respectively.

To sail from the English Channel to the Gulf of Mexico; the great circle track (*E.H.*) is from *E* to *a*, 10°, and (*W.H.*) from *a'* to the southern end of Florida, 52°. Such are our imperfect ideas concerning a sphere and geographical relations, as derived from ordinary maps, that probably few imagine that in sailing the shortest distance from the English Channel to the Gulf of Mexico the course on leaving the Channel would be nearly due west, in fact a little north of west, as shown by figure 14.

From the English Channel to the Strait of Magellan; the track would be (*E.H.*) from *E* to *b*, 27°, and (*W.H.*) from *b'* to *b''*, 54°. The same great circle, if continued, would carry to Cape Horn. To proceed to the Strait of Magellan another track would be taken from *b''*, as shown in figure 11, page 260.

From Northern Luzon, Philippine Islands, to San Francisco; the track is (*E.H.*) from *L* to *c*, 40°, and (*W.H.*) from *c'* to San Francisco, 57°. The course of this great circle, skirting close to Japan and running not far from the Aleutian Islands, is different from what most people would expect from being familiar with seeing the places on a Mercator's chart.

The great circle track from Northern Luzon to the western entrance to the Strait of Magellan is (*E.H.*) from *L* to *d*, 89°, and (*W.H.*) from *d'* to *M*, 55°. The track, as shown on the map, leads through the Philippine Islands and Australia, and quite close to the Antarctic Continent. In order to sail from Luzon to the Strait two great circle tracks may be followed, thus: (*E.H.*) from *L*, keeping north of the Solomon Islands, to *e*, 47°, and (*W.H.*) from *e'* to *e''*, 4°, then from *e''* to *M*, 100°.

Lastly, the great circle track from New York to the Cape of Good Hope is (*W.H.*) from New York to *f*, 64°, and (*E.H.*) from *f'* to the Cape, 50°. Continuing this great circle track around the world, it leads from the Cape of Good Hope across the Indian Ocean, Australia and New Guinea to *f* in the Pacific Ocean, and from *f'* across the Pacific Ocean and the northern United States to New York. One has but to try to trace some great circle tracks on a sphere to appreciate how difficult it is to follow them exactly, while with a map, such as shown in figure 14, and a protractor they may be followed with the greatest ease.

It appears worth while to call attention to an erroneous idea concerning geography which most people brought up in the eastern part of the United States seem to have acquired during childhood, namely, that if it were possible to pass through the center of the earth and come out on the opposite side they would find themselves in China. As shown by figure 14 the

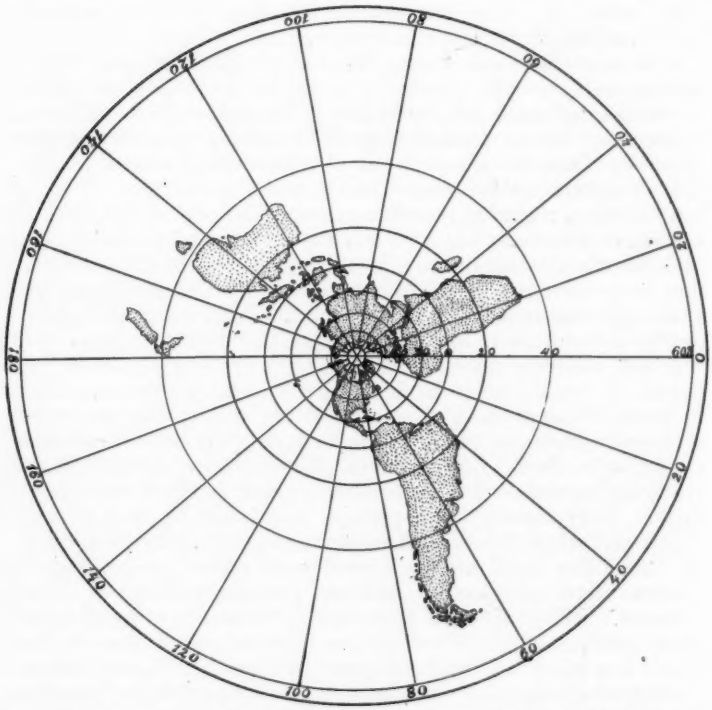
point antipodal to New York is in the Indian Ocean, about 600 miles southwest of Australia.

If the idea of having two hemispheres projected on the same plane appears to some too confusing to be regarded as practical, it may be recommended to have in addition to the customary maps of the western and eastern hemispheres, two additional ones; one with 30° W. as the central meridian, thus giving a chart of the North and South Atlantic Oceans; the other with 150° E. as the central meridian, giving a chart of the North and South Pacific Oceans.

Generalizations concerning Maps of the Hemispheres. Comparison with a Globe.—Before closing the discussion of maps of the hemispheres, it is desired to call attention to a few facts concerning them. Considering their size, projections made upon the plane of the equator or of a meridian, figures 4, 8 and 9, are unquestionably as good and serviceable maps as any that can be made, regarded merely as representations of the earth's surface. When one has once become accustomed to them, and understands the nature of the distortion which they exhibit, they are even more useful than a globe. The writer does not wish to be misunderstood at this point. It is best that beginners should get their first ideas of geography from a globe, and this fact is recognized by teachers, and a globe is placed in the hands of every scholar in our best elementary schools. The small and inexpensive globes which are in common use, however, are necessarily rather crude, and one has but to examine a number of them to discover that the segments of which they are built up have not been pasted on and matched very carefully. They answer their purpose admirably up to a certain point, but when it comes to accuracy they fail. Large globes on the other hand are of necessity expensive, and there is always some question as to how accurately they are constructed. When it comes to studying the details of geography from globes, other difficulties are encountered; thus, if the globe is small, but few details can be shown on it, and only a portion of a hemisphere can be seen at once; perhaps not more than a third to good advantage, while with a large globe the portion seen is still less. In order to study relations where large portions of the earth's surface must be taken into consideration, if a globe is used it must be turned in order to see its several parts, and, even when experienced, it is difficult to keep in mind correct ideas of those portions which are either out of sight or but imperfectly seen. With stereographic maps, on the other hand, a hemisphere may be admirably shown, even the whole world, figure 14. Moreover, there is no difficulty in constructing the maps with extreme accuracy, so that, with suitable protractors, reliable measurements of all

kinds may be made on them. The hemispheres shown in figures 4, 8 and 9 were drawn by the writer with much pains, the diameter of the originals being one foot. They are approximately correct, but by constructing meridians and parallels for every degree, and making use of the best coast surveys, there is no reason why, on a map of a hemisphere one

15



Stereographic Map of the inhabited portions of the World, extending from the North Pole to 60° south of the Equator.

foot in diameter, the outlines of all accurately surveyed land areas should not be traced within a quarter of a degree of their true geographical position. The drawing of the parallels and meridians for every degree should be for the guidance of the engraver; every tenth degree only should be shown on the completed map. The location of cities should be not far from five miles from their true position, and the maps should not be crowded by too much detail. Accurate maps as just described should have distinct educational value, and would open up new

possibilities in mathematical geography. Maps of the hemispheres two feet in diameter would not be too large for convenient use, and they could be engraved with such accuracy that remarkably exact measurements could be made on them.

Stereographic Map including more than a Hemisphere.— All of the inhabited portions of the world may be shown on one map, as illustrated by figure 15, which is a stereographic projection on the plane of the equator, copied from a figure given by G. W. Littlehales,* with omission of some of the

16

Model for illustrating the principle of the stereographic projection upon a plane at right angles to a given diameter.

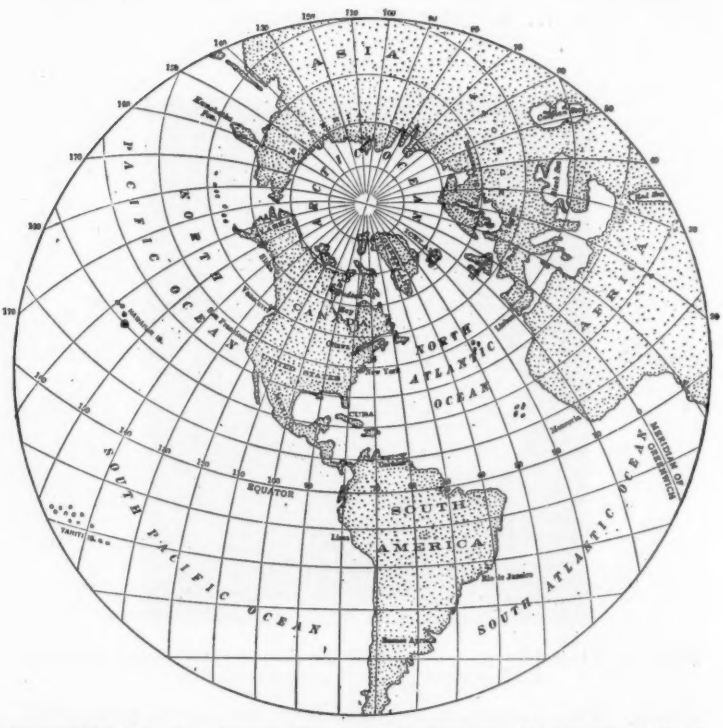
details. The projection extends from the north pole to 60° south of the equator, and distortion on a map covering so large an area is very great. Although the land areas in the southern hemisphere appear grotesquely stretched out, they are probably no more distorted than Greenland on Mercator's projection. It is not suggested that maps of this kind should be used; the illustration is introduced merely to show some of the possibilities of the projection.

Stereographic Projection upon the Plane of a Horizon.— A most important feature of the stereographic projection is

* The Development of Great Circle Sailing, loc. cit., p. 50.

that a map may be made on a plane tangent at any desired point on a sphere, or a plane parallel thereto at the center; and the results are equally satisfactory no matter where the point of tangency may be. As will be shown, the object of making this kind of a map is that any desired region may be projected at the center of a hemisphere, where distortion is

17



Stereographic Map of a Hemisphere upon the plane of the horizon at 40° N., 75° W., near New York City.

least, and where, consequently, a country may be mapped with the best results. Figure 16 represents a model for demonstrating this kind of projection. The skeleton sphere is orientated with the *N. S.* pole vertical, and the meridians and parallels of the upper, front hemisphere are spaced 20° apart. The equator is easily recognized, and it is important to keep in mind two points, one, indicated by a flag, on the parallel 40° N. where it would be intersected by the meridian 95° W., the

other the antipodal point *P*. The plane upon which the map is drawn is at right angles to a diameter running from 40° N., 95° W., to *P*. By reference to an atlas it will be seen that the point where the flag is located, 40° N., 95° W., is near the center of the United States. The model is admirably represented by the figure, and no further description seems necessary.

Figure 17 is a projection upon the plane of the horizon at 40° N., 75° W., very near to New York City. The projection of the parallels and meridians is the same as shown on the

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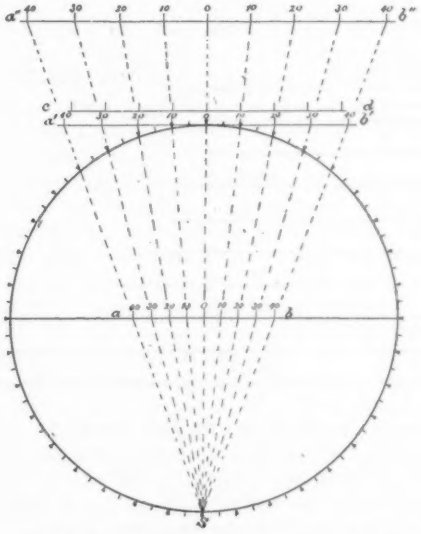


map in figure 16, but the meridians are numbered differently. The parallel 40° S. is a straight line on the map, and why it is thus represented is at once apparent from consideration of figure 16.

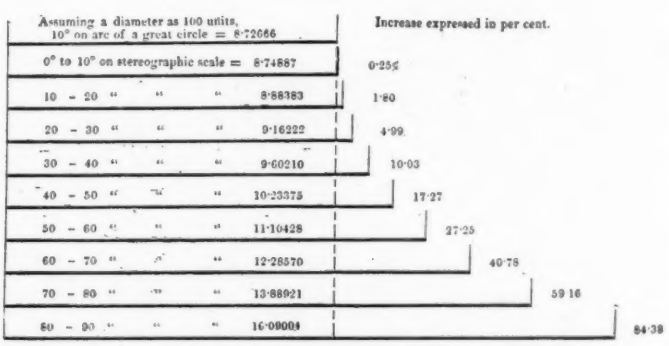
The principle of making a map on a plane tangent at any given point is not so important for the projection of hemispheres as for the mapping of limited areas, and in order to appreciate the advantages of this method of map-making it will be necessary to consider more carefully the character of the distortion near the center of a stereographic projection.

Distortion resulting from the Stereographic Projection.— Figure 18 is a graphical method of representing the distortion. Let the divided circle represent any meridian with 0 as the

north and *S* the south pole. By means of lines running from *S* to the 10° graduation marks of the circle the several points, 40° either side of the center, are projected to the line *a b*, where they fix the points of a stereographic scale. As far as may be told by the eye, the scale *a b* appears equally spaced.

The lines of projection are also continued beyond the circle to the intersection with the tangent *a′ b′*, where a stereographic scale is likewise determined, similar to *a b*, but relatively twice as long; or again the projection may be carried to *a″ b″*, parallel to *a′ b′*, where a similar, but still more lengthened, scale is formed. At *c d* a scale has been interposed which represents spaces equal in length to $\frac{1}{360}$ths of the circumference

19



of the circle, or, in other words, the distances from space to space on the line *c d* are the same as along the circumference of the circle for distances of 10°, following the curvature. Close inspection of the scales *a′ b′* and *c d* fails to show any appreciable difference between the first lines (10°) either side of the center. If therefore a country to be mapped is not over 20° wide, the point of tangency may be taken at its center and the distortion resulting from the stereographic projection will be scarcely appreciable. If a country is 40° wide, at 20° either side of the center there will be perceptible, but still not very great distortion, as indicated by difference in the scales *a′ b′* and *c d*. Even if the distance across a map is 80°, the distortion at 40° from the center is marked only near the periphery, and there it is not sufficiently great to seriously impair the usefulness of the map.

Still another way of representing the distortion is shown in figure 19. If a sphere is 100^{cm} in diameter, its circumference measures 314·15927^{cm}, and 10° of arc would equal 8·72666^{cm}. Considering a map projected upon a tangent plane of such a

sphere, figure 18, a distance 10° out from the point of tangency would be 8·74887^{cm}, or but 0·02221^{cm} longer than the distance of 10°, following the curvature. In like manner in figure 19 other 10° spaces of a stereographic scale are expressed in lengths, carefully plotted to scale, and the accompanying percentages give the increase over the length of 10° of arc. Thus it may be seen that in any of the stereographic hemispheres shown in earlier pages of this article there is greater distortion in the space between 70° and 90°, measured out from the center along a radius, than from the center out to 70°.

The foregoing examples serve to indicate that near the center of a stereographic map of any hemisphere there must be very little distortion, and in order to study the possibilities of a stereographic map of limited area, it was decided to make a projection of the United States on a large scale. The scale adopted was based upon a sphere of 1·8 meters (5·9 feet) radius, supposing the projection as made on a central plane, figure 16, page 269, and this particular scale was chosen in order to give a map corresponding in size with one issued by the U. S. Geological Survey, accompanying the Twenty-first Annual Report of the Director, 1899–1900. The dimensions of the government map are 27½ by 16⅞ inches, and parallels and meridians are drawn two degrees apart. Although not stated, it bears evidence of being based upon the Polyconic Projection which is used by the U. S. Coast and Geodetic Survey. The central meridian is 97° W. and its intersection with the parallel 39° N. is approximately the center of the map.

Projection of a Map of the United States upon the Plane of the Horizon at 39° N., 97° W.—The essential details of making this kind of a map are illustrated by figure 20. The upper circle represents a vertical section (an elevation) through the *N.* and *S.* poles of a sphere, along what is to be the central meridian of the map. As 39° N. is to be the center of the map the *N.S.* pole is inclined 51° (90°–39°) from the vertical, and intersections of the meridian with the equator, *EE'*, the poles *N.S.*, and the trace of the central plane upon which the map is projected, *N'S'*, are indicated by the graduation of the circle. *P*, at 39° S., is the point of vision. Numerous points on the central meridian are *projected* to the line *N'S'*, thus determining points which are needed in the construction of the map. The lower part of the figure represents the plane upon which the map is made, and, taken in connection with the elevation above, may be considered as a *plan*. The line *N''S''*, parallel to *N'S'*, is the projected central meridian, *N''* and *S''* being respectively the stereographically projected north and south poles. The circle *I*, of the same size as the meridian above, would bound the hemisphere, if the latter were fully

constructed. Having fixed the center of the hemisphere, the intersections of the several parallels with the central meridian, $N''S''$, may be projected down from the elevation above, and to find the center points and construct the circles which represent the projection of the parallels on the map scarcely needs

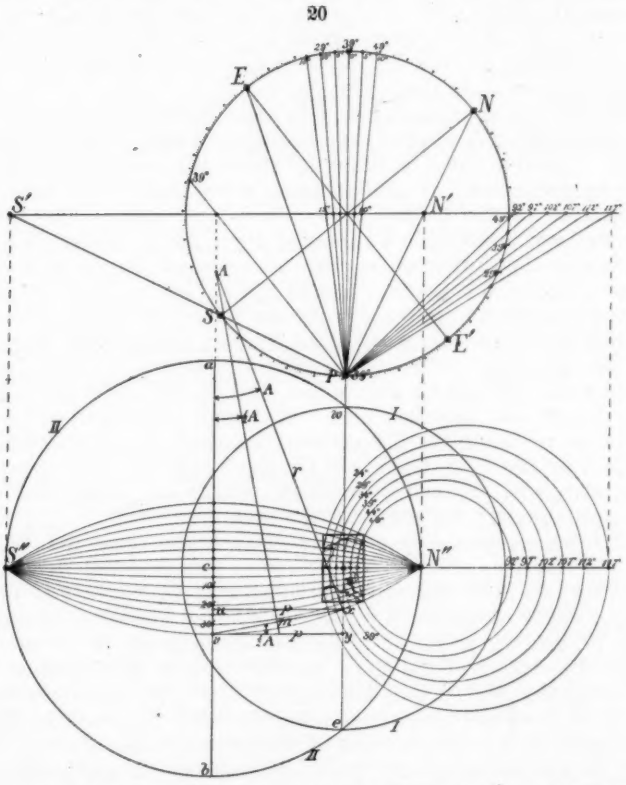


Illustration of the principles upon which a stereographic map of a limited area is constructed.

explanation. When drawing a map on a large scale the several intersections of the parallels with the central meridian, and the lengths of the radii for describing the parallels, are determined by calculation, making use of a table which will be explained at the conclusion of this article. To construct the meridians, the following principles are made use of: They are circular arcs passing through the stereographically projected north and south poles, N'' and S'', and their centers must be on the line

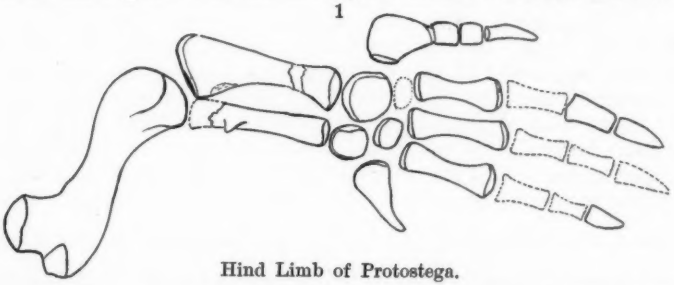
ab, figure 20, crossing the central meridian at 90°, just midway between N'' and S''. The line *ab* is the stereographic projection of the parallel 39° S., which in this case is a straight line because P is at 39° S.; compare the projection of the parallel 40° S., figure 16, page 269. Since angles are preserved in the stereographic projection, the meridian must make equal angles with one another (5°, figure 20) at N'' and S''; hence N'' and S'' may be considered as the poles of a projection on the plane of a meridian having a diameter $N''S''$, and the construction of the meridians is the same as described on page 256. In drawing a map, such as that of the United States, on a large scale, the location of the meridians and their curvature must be determined by calculation, and one example will illustrate how this may be done: On the diameter *ew*, passing through the center of the map at right angles to the line $N''S''$, it is desired to find the point x where that meridian intersects it, which is 35° from the center of the large circle II. Knowing the radius of the large circle II, the radius r, for describing the meridian which intersects the diameter *ab* at 35° from the center, may be found from a table described at the close of this article. A right triangle Aux may then be constructed, in which the hypothenuse r and the perpendicular p (equal to the distance from c to the center of the map) are known; hence from sine $A = \frac{p}{r}$ the value of A may be found. Construct the chord vx, and from its center m draw a line to A; the line mA bisects the angle A. Also it follows from the construction that in the triangle xvy the angle at v is equal to $\frac{1}{2}A$; hence tangent $\frac{1}{2}A = \frac{xy}{p}$, from which the value xy may be calculated. The distance cv being known, and equal to the distance from the center of the map to y, the distance from the center of the map to x is readily determined.

A method like the foregoing was used in plotting the meridians of a large stereographic map of the United States. In addition to a construction line drawn through the center of the map, corresponding to *ew*, figure 20, two other lines were drawn parallel to *ew* at measured distances, one crossing near the top, the other near the bottom of the map. The points of intersection of the several meridians with the three construction lines were then calculated, and each meridian was drawn through the three points thus determined, making use of a large circular arc ruler. The calculation was not especially laborious, since only simple formulas were used, and the same quantities were repeated several times, so that to a certain extent the work becomes almost mechanical.

[To be continued.]

Art. XXII.—*On the Hind Limb of Protostega;* by S. W. Williston.

Although the structure of those huge Cretaceous turtles, *Protostega* and *Archelon*, has been, for the most part, determined in recent years through the researches of Baur, Hay, Case and Wieland, little has hitherto been discovered concerning the limbs, aside from the humerus and femur. In examining the material of *Protostega* in the University of Kansas museum recently, I found a nearly complete hind limb collected by Mr. Charles Sternberg in the Kansas chalk two years ago. This is of so much interest that I give herewith a brief description and outline figure of it. The species is, I



Hind Limb of Protostega.

suppose, *P. gigas*, though I do not feel certain. Among the various specimens of this genus I have examined there is a great difference in size, a character of doubtful value for specific separation, as well as distinct differences in the shape of the limb bones. The present specimen, for instance, is among the largest discovered in the Kansas chalk, and has the femur much more slender than in the specimen figured by Case (Journal of Morphology, June, 1897, pl. vi, f. 18).

The specimen had been, for the most part, washed from its matrix, and the original relation of the different bones lost, but since only the posterior part of the skeleton is present they all clearly belong to the hind limb. The bones of the fore limb, moreover, are all much larger than those of the hind. Some of the phalanges were lost and probably one of the tarsals. In the figure I have arranged the bones as they would seem to belong, though very likely some of the metatarsals and phalanges had different positions in the living skeleton.

For a review of the discussion as to the systematic position of *Protostega*, the reader is referred to the paper by Professor

Case cited above. The relationships to *Chelone* and *Thalassochelys* pointed out by Baur, Hay and Case receive additional confirmation from the structure of the limb, as will be seen in the accompanying figure. The leg, while broader and more powerful, is not essentially different in structure from that of *Thalassochelys*, and it would seem that there could hardly be longer a question as to the relationship of these forms,—*Protostega* and *Archelon*, at least,—to the Cheloniidae.

The characters separating *Archelon* Wieland from *Protostega* Cope, while not very important, would seem sufficient. Nevertheless, one can derive little justification from the difrent geological horizons in which the forms are found. The relations between the Niobrara and Fort Pierre vertebrates are for the most part very close. I have recognized in both horizons *Tylosaurus*, *Platecarpus* and *Mosasaurus* (*Clidastes*), as well as *Pteranodon* and *Hesperornis*, all very typical of the Niobrara deposits, and the existence of *Claosaurus* has been recently affirmed in the Fort Pierre. On lithological grounds, there is nothing separating the two groups of deposits, and I protest against the names Colorado and Montana, as perpetuating a wrong impression. On paleontological and lithological grounds there would be much better reasons for uniting the Niobrara with the Fort Pierre than with the Fort Benton.

Description.—The head of the femur is large, and, in life, evidently nearly hemispherical. The neck is very stout, placed at nearly right angles to the axis of the shaft and is but slightly constricted. The trochanter is large, and stout, with a large, triangular, roughened area on the posterior side for muscular attachment. The smaller trochanter is indicated by a small tuberosity. The shaft is much constricted and curved, with its convexity dorsal; it is nearly cylindrical at its middle part. The condyles are large and stout, the inner more massive than the outer one; their articular surface looks nearly backward. The tibia is much expanded superiorly, and has its articular surface at an angle of about 45° with the axis of the shaft. On its posterior surface, and margin, a little below the angle there is a strong muscular rugosity. The shaft is much narrowed below, and is again moderately expanded for the distal articulation.

The fibula is elongated and narrow, of nearly uniform width, except at the upper extremity. This portion of the bone is wanting in the specimen but that portion preserved indicates a moderate expansion superiorly. On the posterior surface, opposite the roughening of the tibia, there is a strong rugosity, produced into an angular tubercle, for muscular attachment.

Three tarsal bones are preserved, and there was probably

one more not recovered. They are all rounded and flattened. The largest, apparently the tibiale, shows a thickened cartilaginous border on three sides, elsewhere thinned. The next larger tarsal, probably the fibulare, is somewhat thicker, and has the thickened cartilaginous surface encompassing nearly the border. The third bone, the smallest, and probably belonging in the distal row, is a more thickened nodular bone, oval in shape with one side much thickened for cartilage.

The metatarsal of the first toe is a thin, broad, hatchet-shaped bone, with a proximal thickened articular border for union with the tarsus, a smaller distal surface for phalangeal articulation, a thickened, concave inner border and a strongly convex, thin, outer border.

The three metatarsals belonging to the second, third and fourth toes are moderately slender, with the extremities moderately expanded. Their relative positions I cannot give positively, but I have arranged them in the figure as they would seem to belong. They differ only a little in length; two of them have one border nearly straight, the other concave, while the shortest and stoutest has both borders markedly concave. The fifth metatarsal bears no phalanges. It is a slender, triangular bone flattened proximally, where it articulates with the tarsus; curved, cylindrical and pointed distally. It evidently was much divaricated in life.

The phalanges of the first toe were three in number, the first two short, thickened, with a concave proximal and convex distal extremity. The ungual phalanx I believe to be the slender pointed one of the three preserved. The other ungual phalanges preserved, two in number, were less slender, one much smaller than the other. One other phalanx is known, a rather short and but little constricted bone, apparently belonging in the second row.

Measurements.

Length of femur	360mm
diameter of head	95
diameter of shaft	60
Length of tibia (somewhat approximate)	270
Greatest diameters of tarsals	90, 65, 55
Length first metatarsal	110
Length fifth metatarsal	130
Lengths second, third and fourth metatarsals	140, 155, 170

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Art. XXIII.—*The Physical Effects of Contact Metamorphism;* by Joseph Barrell, Ph.D.

Introduction.—Although much has been developed in past years concerning the physical, chemical and mineralogical effects of the metamorphism produced in sedimentary beds by the contact of igneous masses, but little has been said concerning the wholesale liberation of gases from the sediments so affected, attended by shrinkages of volume and the possible results in the formation of vein fissures, impregnation deposits and new intrusion of igneous matter, owing to these causes and the changes in pressure which accompany them. Certain of these questions were suggested to the writer in 1899 while studying the geology of the Elkhorn District in Montana as a field assistant for the U. S. Geological Survey, and the following article was written in the petrographic laboratory of the Sheffield Scientific School of Yale University under the supervision of Prof. L. V. Pirsson as one chapter in a thesis on the Geology of the Elkhorn District, prepared in partial fulfillment of the requirements for the degree of doctor of philosophy.

Excluding for the moment the possible impregnation and metasomatic effects of mineralizing vapors and heated waters carrying dissolved materials into the contact rocks, the chemical effects consist in the more or less complete expulsion of carbon dioxide and combined water and the formation of the remaining constituents into new minerals. In addition, there are physical effects of considerable magnitude; the strata not only assume a greater hardness and density, but in beds of certain compositions it will be shown that there may be a shrinkage of from 25 to 50 per cent. in volume, attended with the evolution of great quantities of gases which at surface pressures and temperatures would amount to several hundred times the volume of the original sediments.

The reasons why such changes in volume have not been noted in the field probably lies in the special compositions necessary to produce the most striking effects and the fact that intrusions have often greatly disturbed the adjacent strata.

The kinds of rocks which will be least affected are those of igneous origin. In the presence of later intrusives and disregarding the temporary expansions due to the high temperatures, these will naturally suffer no appreciable change in volume and none at all in mass. The most that would be expected to occur would be the acquisition of certain characteristics due to the minerals having been exposed to long and intense reheating. On the other hand, those subject to the

greatest changes in volume and mass are carbonate rocks containing sufficient silica to combine with all the bases, to the complete expulsion of the carbon dioxide.

To determine with some degree of precision the extent of these metamorphic changes, it becomes necessary to know quantitatively the degree to which decomposition, disintegration and sedimentation affect the rocks upon which they operate. To that end the nature of these processes will first be briefly reviewed and then the completeness with which they are commonly carried out.

The Decomposition of Rocks.

All the materials of the earth's crust which exist combined with carbon and hydrogen as carbonates and hydrates have supposedly been formed as a result of the decomposition of silicates and were once components of igneous rocks. In determining the final form in which the sediments occur two classes of action have been operative in separating the components of the igneous rocks. First, the difference in the rate of decomposition of different minerals by which the alkalies and alkaline earths are taken into solution. Secondly, the forces of transportation and sedimentation which in operation effect a more or less complete separation, gathering together the quartz as beds of sand and the particles of clay as mud banks. Since this discussion is confined to general conditions and roughly quantitative results, it is only necessary to consider the common rock-making minerals of the igneous rocks, the source of all the materials of the stratified series, though several cycles of erosion, sorting and sedimentation may have intervened between the igneous origin and the existing sediments.

The minerals necessary to consider are quartz, alkali feldspars, lime-soda feldspars, micas, hornblende and pyroxene, and the disseminated iron ores. Under the conditions of heat and pressure attending their formation they are naturally the most stable minerals. With the lowering of the temperature, however, and especially in the presence of meteoric waters bearing carbonic acid, other products possess maximum stability and the original minerals are susceptible to change in varying degrees.

The study of rock decomposition was undertaken long since by Daubree, Bischof, the Rogers brothers and others, and has latterly been studied and supplemented by G. P. Merrill*. From the articles of the latter many of the following statements have been drawn.

* Bull. Geol. Soc. America, vol. vi, p. 321, vol. vii, p. 349; Journal of Geology, vol. iv. p. 704 and p. 850; Rocks, Rock Weathering and Soils (The Macmillan Co.).

The Rogers brothers found in 1848 that nearly all of the common silicate minerals were readily attacked by water carrying carbonic acid, and Richard Müller in 1877 gave quantitative determinations on a number of the common species. The alkalies, lime and magnesia are dissolved as carbonates. The iron in the case of hornblende, epidote, etc. passed into ferric oxide upon evaporation of the solutions. In the action of carbonated waters upon alkaline silicates like the feldspars a limited amount of silica always goes into solution, presumably in the form of hydrate. Olivine is dissolved with considerable rapidity, and other magnesian silicates, including serpentine, are also attacked. It is found that increase of pressure renders the action more energetic. Bischof states that the alkaline silicates lose their alkalies readily to carbon dioxide with separation of free silica. If the alkaline carbonates subsequently meet lime silicates, a replacement is effected whereby the alkalies are for the time being retained in the soil, presumably as hydrous silicates, such as the zeolites.

Water not only acts as a conveyor of carbonic acid but in itself is efficient in the process of rock decay, by entering as water of crystallization into a large number of minerals of more or less stability, such as the zeolites, chlorites, serpentine, talc and kaolin.

The oxygen dissolved in water serves to precipitate hydrated ferric oxide from ferrous carbonate solutions. It is to be noted that the greater part of the hydrous silicates are pre-eminently subterranean and not sub-aerial minerals, a free exposure of oxygen, water and carbonic acid eventually destroying them.

From the original igneous minerals, then, it may be stated that weathering carried to its limit would produce as solids quartz, kaolin, limonite, calcite and magnesite, the latter combined with the calcite as dolomite; and would cause to be taken into solution all the alkalies and some of the alkaline earths. But although this is the theoretical limit of weathering, it is questionable how nearly it is ever reached.

The extreme solubility of soda feldspars over the potash one is well known. In fact, under normal conditions of weathering, orthoclase is one of the most resistant of rock-making minerals. It is true also that nearly all unmetamorphosed sediments show some protoxides which are still existent as silicates. Some idea can be gained in a general way as to the extent to which decomposition accompanies disintegration, and an examination of the unmetamorphosed sediments in thin section aided by an analysis would determine the degree for any special case. Two extremes of decomposition will be briefly considered: first *in situ*, the minimum amount neces-

sary for the disintegration of a rock, and secondly that found in material which has suffered long transportation and trituration, such as the residual clay from a limestone.

Amount of Decomposition in situ.—Merrill has shown in the articles to which reference has been given that in the instances studied by him the transition from fresh rock to soil *in situ* has been brought about with very little change in ultimate chemical composition—an addition (in the case of the Washington granite) of some 3·5 per cent of water, a change of the ferrous iron to ferric, doubtless more or less hydrated, and a slight decrease in the total amounts of silica, lime, potash and soda being the more conspicuous features. "It is evident that here the chief alteration in the conversion of the barren rock into arable soil is physical, attended probably with a partial change in the mode of combination of the various elements."*

In his investigation upon the changes taking place from fresh rock to soil *in situ* a separate analysis was made of the impalpable mud or silt derived from the soil and remaining some time in suspension in water. Of this, representing 4 per cent of the total disintegrated material, only 39·7 per cent was soluble in dilute hydrochloric acid, and a considerable proportion of the residue, as indicated by the high percentages of alkalies and lime, still consisted of unaltered soda-lime and potash feldspars, the iron and magnesia alone having been largely removed. This power of the alkaline feldspars to strongly resist decomposition, even when finely divided, is to be noted, since the study of thin sections under the microscope shows that one of the common earliest results of rock decay is the filling of the feldspars with sericite flakes or kaolin dust. From this fact alone it would be judged that the feldspars upon disintegration to an impalpable mud would be readily converted to kaolin, the final product of alteration; yet such proves not to be the case, a considerable proportion of them remaining unaltered and therefore suffering no loss of components when subjected to metamorphism.

Decomposition in Transportation and Sedimentation.—In the undisturbed soil of an igneous rock, however, the fullest opportunities have not yet been given for hydration, oxidation and the formation of carbonates. To test the limit to which such actions proceed under favorable circumstances, instances should be studied where transportation and sedimentation have given the fullest opportunities for complete alteration.

The residual clay from a limestone meets the requisite conditions, having been finely comminuted and subjected for a long period of time to such agencies before settling to the

* Bull. Geol. Soc. America, vol. vi, p. 324.

ocean bottom. During the existence of the unaltered limestone the impurities would be in part protected from further decomposition by the stronger affinity of the lime for the carbonic acid contained in the percolating waters, forming soluble bicarbonates. After the solution of the lime, however, the insoluble materials would form a residual clay soil, and as long as their existence in that state continued, the water and carbonic acid would tend to effect a change into hydrates and carbonates.

In Bulletin 148, U. S. Geological Survey, page 389, are three analyses of such a residual clay, and given below. The three analyses furnish considerable data for the determination of the combinations in which the elements exist, but such an elaborate discussion is not necessitated by the work in hand. They are by George Steiger and are as follows:

ANALYSES OF CLAY, STAUNTON, VA.

	B	C	D
SiO_2	55·90	3·09	52·81
TiO_2	·20	·04	·16
Al_2O_3	19·92	3·96	15·96
Fe_2O_3	7·30	6·25	1·05
FeO	·39	·30	·09
MnO	none	----	----
CaO	·50	·30	·20
MgO	1·18	·43	·75
K_2O	4·79	·28	4·51
Na_2O	·23	·20	·03
H_2O at 110°	2·54	----	----
H_2O above 110°	6·52	2·10	4·42
P_2O_5	·10	·04	·06
CO_2	·38	·38	none
	99·95	17·37	80·04

B. Residual clay from limestone, Staunton, Va.
C. Portion of B soluble in weak hydrochloric acid.
D. Insoluble portion of B.

These analyses are particularly favorable for testing the decomposition of the feldspars, there being large amounts of silica, potash, alumina, ferric oxide and water present and relatively small amounts of other components; hence errors in considering the state of combination of the latter will have but a minor effect upon determining the form in which the alkaline silicates are present.

The fully hydrated form of aluminum silicates is kaolinite, and this is the state toward which the weathered products of the feldspars approach, the fully hydrated form of the ferric

oxide being limonite. The ferrous oxide, magnesia, lime, titanium oxide, and phosphoric pentoxide may also exist more or less fully hydrated.

Computing on this basis how much combined water would exist in the clay of analysis B if it were fully decomposed and hydrated, the following is obtained:

	Per cent of elements in clay. Anal. B.	Per cent of water, if fully hydrated.
Al_2O_3	19·92	7·0
Fe_2O_3	7·30	1·2
FeO, CaO, MgO, P_2O_5, TiO_2	2·37	0·5
H_2O above 110° found.	6·52	required 8·7

From this table it is seen that in this clay, subjected as it has been to most extreme conditions of weathering, the constituents are not more than three-fourths fully hydrated.

The same conclusion may be reached by looking over various reports on clays. The composition of kaolinite is: silica 46·5, alumina 39·5, water 14·0, the ratio of water to alumina being 35 per cent, yet it is seldom that more than 80 per cent of the full amount of combined water is present.

The Limits of Decomposition.—To sum up the foregoing discussion it may be stated that, disregarding the infiltration of elements from without, the quartz sand present in a sediment exists in its original state: the amounts of alkalies present are a measure of the incompleteness of decomposition, since upon complete weathering they are removed. If alkalies are present, some of the lime may be combined with the soda as a plagioclase feldspar, and the magnesia, in a similar manner, may exist in combination with the potash as a mica. In certain hydrous silicates small amounts of lime and magnesia may be also combined with alkalies. But beyond these small amounts they exist as carbonates and their final stage of alteration has been reached. The alumina is not usually more than three-fourths fully hydrated to kaolinite.

From these statements it is seen that the amount of combined water may be taken as an indicator of the completeness of weathering.

Changes of Mass and Volume in Metamorphism.

Expulsion of constituents and loss of mass.—It is commonly observed that metamorphosed strata are composed of certain mineral species, most of which show habits characteristic of these rocks.

A few metamorphic minerals, such as epidote, vesuvianite and biotite, may carry as much as 2 per cent of combined water. With such exceptions the water is uniformly and completely expelled, and by that amount in which it was contained in the original strata the mass is lessened. Carbonic acid is only expelled where the siliceous impurities of the limestone are sufficient to combine with the lime set free, forming lime silicates. This ability of deeply-buried limestones to retain their carbonic acid when intensely heated, if free from other impurities, has been noted by a number of observers, and is well shown in the Elkhorn district, Montana, where marbles in some cases exist within two to four feet of the granite contact, having retained their carbonic acid under temperatures which at the surface would have led to its immediate expulsion. In a general way the losses may be tabulated as follows:

Pure Types.	Loss in Weight.
Sandstones	0 per cent.
Claystones	4 to 10 " "
Limestones	0 " "
Mixed Types.	**Loss in Weight.**
Arenaceous claystones	2 to 6 per cent.
Arenaceous limestones	5 to 30 " "
Argillaceous limestones	5 to 23 " "

In addition to the above, the greater *porosity* of the unmetamorphosed sediments enables them to retain a larger amount of hydroscopic moisture, to be expelled along with that in chemical combination.

Loss of volume.—The losses in volume are still more striking than those of mass, and are due to three causes. First, decreased porosity; second, losses of water and carbonic acid; third, crystallization into minerals of greater density. The porosity or amount of vacant space of rocks of the same composition may vary within quite wide limits, sandstones running from 5 to 28 per cent, limestones 0·2 to 13 per cent, shales probably from 5 to 15 per cent. The various kinds of hornfels probably possess a porosity of from 0·5 to 3 per cent. Taking the differences between the original and resulting porosity, the losses in volume from this source, by metamorphism in a general way, may be set down as follows:

Kinds of rocks.	Loss in Porosity.
Sandstone to quartzite	5 to 15 per cent
Argillaceous sandstone to hornfels	5 " "
Impure limestones to hornfels	1 to 5 " "

It will be shown later that the losses in volume due to the other two causes may amount to as much as 47 per cent. Thus occasionally the combination of the three may result in a shrinkage of the strata by as much as 50 per cent upon the intrusion of a neighboring igneous mass. The geological consequences of such striking changes may well be studied in some detail.

Relation of metamorphic minerals to original composition.—From the species and proportionate amounts of the metamorphic minerals seen in thin section, it will be desirable to determine the nature of the original sediments and thence the changes undergone in mass, volume and mineral composition. Leaving aside for the present those possible accessions connected with impregnation and fumarole action, the chemical elements will remain present as before stated except for the expulsion of a greater or less quantity of water and carbonic acid. To determine this relation of metamorphic minerals to original composition, some definite basis must be adopted. For that reason the sediments are assumed to consist of a number of stable minerals, the results of thorough decomposition. As has been shown, in argillaceous rocks such a condition is never perfectly reached, and where such have suffered changes the losses computed on the above basis must be diminished by a factor depending upon the incompleteness of the decomposition of the original rock. In strata consisting of quartz sand and carbonates, however, the changes will be strictly those shown by the following table.

The metamorphic minerals given in the table, except for the omission of biotite, are those of commonest occurrence in strata adjacent to igneous rocks. Biotite, though of common occurrence as a result of metamorphism in rocks of an arenaceous-argillaceous character, has such a complex composition that it is useless to attempt to compute from what materials it has come, unless something is known of the unmodified strata. The ferrous oxide, magnesia and alkalies present in biotite, furthermore, are indicative of an incompletely decomposed sediment, and add to the difficulties. The absence of biotite from the table for that reason, however, is not a serious matter, since the materials forming it have possessed but little carbon dioxide and a medium amount of water and consequently in metamorphism have not changed greatly in volume or mass. While the table shows in a general way and with a fair degree of accuracy the changes taking place to produce such minerals; for any special application it may be necessary to extend it in order to take in materials in the original sediments not here considered. The computations have been carried out with accuracy to the final digit and

therefore the only inaccuracies which would attend its use would be from a lack of definite knowledge in regard to the original and final composition of the sediments of any particular case.

It is seen from the above table that wollastonite is produced from a siliceous limestone, diopside from a siliceous limestone containing some quartz. Vesuvianite commonly has a small part of its alumina replaced by ferric oxide, but here it is computed on an iron-free basis. It is seen to be produced by a sediment not far in composition from that yielding grossularite, and has been observed together with it in rock sections.

In epidote the aluminum and iron are interchangeable, the molecular ratio of the two varying from 6 : 1 to 3 : 2. For this reason both zoisite, the iron free epidote, and also the alumina free epidote molecule have their relations shown to the original sediments. If it is desired to find what sediments would furnish a given compound of the two molecules, it may be done by considering the ratio which is present in the mineral of the zoisite to iron epidote molecules and their respective molecular weights, that of zoisite being 455, alumina free epidote 451. In the same way any mixture of the albite and anorthite molecules may have its relations determined, the data of each being here given.

The soda which is frequently shown to exist in hornfels by the presence of a soda-lime feldspar may have existed in unmetamorphosed strata in a variety of forms. In fresh material it might occur as a soda-lime feldspar or feldspathoid, but these being somewhat readily decomposed it would more naturally be anticipated as a hydrous silicate, especially as a zeolite. Merely to show in a general way the relations between an albite occurring in a hornfels and the zeolite minerals, analcite has been selected.

Orthoclase, being a mineral which often occurs in minor quantities in hornfelses, has been introduced for the sake of completeness. The greater part of it has probably come from yet undecomposed though finely comminuted orthoclase, which under the conditions of metamorphism has collected into definable crystals. Another part, however, is no doubt furnished by some of the many hydrous alkaline silicates reacting with other materials.

Andalusite is seen to result from a clay upon the expulsion of the combined water, and is attended by the separation of a large amount of free silica, being the only mineral here considered which does not come from the union of two or more minerals of decomposition, but on the contrary breaks into two minerals during the process of metamorphism. Under that part of the table called "Results of Meta-

TABLE OF RESULTS.

Metamorphic Minerals.									Original Sediments.							Results of Metamorphism.								
	Composition.															Comp. by Weight. Sediments = 100.			Comp. by Vol. at 0° C. and 760 mm. Sediments = 1·00.				Per cent loss to strata.	
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O	H_2O	Quartz.	Kaolinite.	Magnesite.	Calcite.	Limonite.	Orthoclase.	Analcite.	Meta. Min.	CO_2	H_2O	Meta. Min.	CO_2	H_2O vapor.	H_2O fluid.	Wt.	Vol.
Wollastonite	51·7	----	----	----	48·3	----	----	----	37·5	----	----	62·5	----	----	----	72·5	27·5	----	0·672	363·	----	----	27·6	32·8
Diopside	55·6	----	----	18·5	25·9	----	----	----	39·0	----	28·6	32·4	----	----	----	70·2	29·8	----	0·576	409·	----	----	29·8	42·4
Grossularite	40·0	22·7	----	----	37·3	----	----	----	9·8	41·7	----	48·5	----	----	----	72·8	21·4	5·8	0·531	276·	182·	·15	27·2	46·9
Vesuvianite, iron free	37·1	19·1	----	----	41·6	----	----	2·2	10·9	35·0	----	54·1	----	----	----	72·9	23·8	3·3	0·550	310·	103·	·08	27·1	45·0
Zoisite	39·7	33·7	----	----	24·6	----	----	2·0	0·3	65·7	----	34·0	----	----	----	77·5	14·9	7·6	0·595	191·	237·	·19	22·5	40·5
Epidote (iron molecule)	33·3	----	44·3	----	20·7	----	----	1·7	27·3	----	----	30·2	42·5	----	----	81·9	13·3	4·8	0·703	203·	178·	·14	18·1	29·7
Orthoclase	64·7	18·4	----	----	----	16·9	----	----	----	----	----	----	----	100	----	100·0	----	----	1·000	----	----	----	----	----
Albite	68·7	19·5	----	----	----	----	11·8	----	21·5	0·2	----	----	----	----	78·3	93·5	----	6·5	0·821	----	186·	·15	6·5	17·9
Anorthite	43·2	36·7	----	----	20·1	----	----	----	0·3	71·8	----	27·9	----	----	----	77·7	12·3	10·0	0·729	158·	313·	·25	22·3	27·1
Andalusite	36·9	63·1	----	----	----	----	----	----	----	100·	----	----	----	----	----	62·9	SiO_2 23·2	13·9	Andal. & Quartz. 0·730	----	429·	·35	13·9	27·0

morphism" the percentages of the constituents are given into which the sediments break up in the production of the metamorphic mineral.

The latter is the only one of them remaining in the strata, the others escaping as gases, and thus its percentage indicates the amount of shrinkage.

On being set free the gases expand to many times the original volume of the sediments, the numbers in the table being the volume to which they expand at 0 degrees centigrade and 760 millimeters pressure, the unit being the original volume of sediments. In computing the volumes of the metamorphosed strata, the porosity factor, being a variable quantity, has not been included, but nevertheless it is seen that in all cases the shrinkage in volume is greater than the shrinkage in weight.

* Since to use this table it may sometimes have to be supplemented, the method of computation is given below:

Grossularite, $Ca_3Al_2(SiO_4)_3$
SiO_2 40·, Al_2O_3 22·7, CaO 37·3 per cent.
Silica, SiO_2, mol. wt. 60·
Kaolinite, $H_4Al_2Si_2O_9$, mol. wt. 258·8.
$2H_2O=36$, $Al_2O_3=102·8$, $2SiO_2=120$.
Calcite, $CaCO_3$, mol. wt. 100.
$CaO=56$, $CO_2=44$.

Using grossularite as a basis of computation.

$22·7\times\frac{258·8}{102·8}=57·2$; amt. of kaolinite required by 100 parts of grossularite.

$57·2\times\frac{120}{258·8}=26·5$; amt. of silica brought in by kaolinite.

$57·2\times\frac{36}{258·8}=8·0$; amt. of water brought in by kaolinite.

$40-26·5=13·5$; amt. of free silica required by 100 parts of grossularite.

$37·3\times\frac{100}{56}=66·6$; amt. of calcite required by 100 parts of grossularite.

$66·6\times\frac{44}{56}=29·3$; amt. of carbon dioxide brought in by calcite.

Thus:—

57·2	Kaolinite	yields	100·	Grossularite.
13·5	Quartz		8·0	Water.
66·6	Calcite		29·3	Carbon dioxide.
137·3	Sediments		137·3	

Bringing this to a basis in which the amount of sediments shall form the unit gives the following figures:—

100 parts of sediments consisting of 41·7 kaolinite, 9·8 quartz and 48·5 calcite yield 72·8 parts of grossularite, 21·4 carbon dioxide and 5·8 of water, as shown in the table.

To compute the volumes divide each weight by the specific gravity of the substance, giving the ratio of volumes. Add together those forming the original sediments and compare with the volumes of the several products of metamorphism. The computation for grossularite is as follows:—

Consequences of the Escape of Gases.

Degree to which metasomatic additions are prevented.—From sediments of suitable composition the escape of these large quantities of gases can not be questioned, but it may be asked how much material, especially silica, may be added to the rock mass by circulating heated waters and thus the shrinkage in volume be in part prevented. The question has greater force since such transfer of material is believed to take place where rocks are brought within the zone of weathering, large amounts of silica being taken into solution and carried downward and away from surface action to be deposited in a zone of cementation.*

The extent to which this takes place in contact metamorphism can best be judged by field observations. Harker† has noted in the metamorphic zone observed by him that the distance of transfer of material has not exceeded one-sixteenth of an inch and the writer has noted similar features at a number of localities near the Boulder batholith in Montana. In the latter region a number of separate intrusions broke through the sedimentary rocks in the early Tertiary and the igneous activity finally culminated in the eruption of the Boulder batholith, a mass of granitic rock which under the present depth of erosion possesses a surface extension of seventy miles in latitude by forty in longitude. At‡ Elkhorn the granite contact breaks on the whole across the strata, at right angles to the strike, so that the metamorphic action may be observed on sediments of widely differing composition. Within three or four feet of the contact, absorption effects from the granitic magma are sometimes observed, but beyond this narrow limit no addition of material is to be noted.

The metamorphism has transformed the purer sandstones into massive lustrous quartzites sometimes shattered by a mesh of aplite dikelets, but showing nothing but quartz and dis-

9·8÷2·6	= 3·8	; vol. of quartz.
41·7÷2·5	=16·7	; vol. of kaolinite.
48·5÷2·6	=18·7	; vol. of calcite.
——	39·2	; vol. of sediments.
72·8÷3·5	=20·8	; vol. of garnet.
21·4÷ ·00197	=10830	; vol. of carbon dioxide.
5·8÷ ·00081	= 7148	; vol. of water vapor.

Dividing each of these volumes by 39·2, to compare them to the volume of the sediments as a unit, gives the composition by volume as indicated in the table.

*C. R. Van Hise, Metamorphism of Rocks and Rock Flowage, Bull. Geol. Soc. Amer., vol. ix, p. 282.

†A. J. Harker, Quart. Jour. Geol. Soc., vol. xlix, p. 368.

‡Geology and Ore Deposits of the Elkhorn Mining District, by Walter Harvey Weed, with an appendix on the Microscopical Petrography, by Joseph Barrell, 21 Ann. Rpt. U. S. Geol. Surv., p. 400.

proving the addition by circulating waters of any basic elements. Pure limestones in the same vicinity and but four feet from the granite mass are converted into white, coarsely granular marbles, whose only impurities are 5·0 per cent of wollastonite in scattered microscopic crystals and 4·5 per cent of some other mineral now completely decomposed. This indicates the presence of not more than 5 per cent of silica in the marble and shows that no appreciable addition to it has taken place.

As these are rocks, however, from which no liberation of gases with shrinkage has taken place, a better test is to observe the changes in the Cambrian limestone, Starmount formation, of the same district. These rocks where metamorphosed have an average composition as follows:

	Per cent.
Grossularite garnet	60·
Diopside	25·
Wollastonite	15·
	100·

This gives a total silica percentage to the rock of 47 per cent. The garnet consists of grains ·05^{mm} diameter, clustered together in areas and also scattered through the intervening minerals, colorless in plain light and taken to be grossularite, though the pyrope molecule may occur to some extent.

The diopside is later than the garnet and is ophitic over areas of from 5 to 10^{mm}. Thirdly, the wollastonite, youngest in generation, is ophitic in similar manner to the diopside. The rocks are dense and even-grained and without cracklings or infiltrations of quartz or calcite. The thin sedimentary banding is still preserved with the same lenticular, somewhat concretionary structure observed at a distance from the igneous intrusions, and the adjacent layers, where of different mineral composition, are sharply separated from each other. Certain strata may show a few per cent of calcite, but this is distributed in a manner which indicates that it is not a secondary addition, but on the contrary is due to those beds containing originally more calcium carbonate than could combine under metamorphic action with the quartz and kaolin present. These features sharply separate the mass of Starmount strata from certain beds, which owing to special conditions do show infiltrations, as indicated by nuclei of quartz with fluorite and ore grains.

The metamorphism in rocks such as the Starmount siliceous and argillaceous limestones is strongly marked for distances of

a quarter to half a mile from the intrusions and in a minor degree extends much farther.

The final test of shrinkage and absence of infiltration would be to measure a section of these rocks and to examine their chemical composition beyond the limits of the district where free from metamorphism, and to compare these results with similar data derived from the metamorphic zone. To do this with the necessary accuracy, however, would have required much time, and the limits of the field season did not permit of the work being undertaken.

From all the evidence at hand it does not appear that except in local and special instances any infiltration has occurred. By referring to the table of metamorphic minerals previously given, it is found that the minerals of the Starmount formation in their observed proportions would originate from a sediment originally consisting of:

Quartz	21·3	
Kaolinite	25·0	
Calcite	46·6	
Magnesite	7·1	combined with calcite as dolomite.
	100·0	

In the process of metamorphism this mass of strata has lost approximately 28 per cent of its weight and 45 per cent of its volume, from 70 to 90 times its volume of water vapor and 320 volumes of carbon dioxide, the gases being measured at 0° C. and 760^{mm}.

The prevention of infiltration.—The causes preventing the addition of solid material are doubtless to be found in the fact that the gases must escape and that while this is taking place recrystallization is going forward; so that by the time relief is obtained from internal pressures and heated waters would be able to make their way inward, the rock is already dense and crystalline. To realize the degree of pressure exerted by the escaping gases it is necessary to state more exactly the conditions obtaining. The individual igneous intrusions may be presumed to break through the strata with considerable rapidity and at temperatures of 1200° C. to 1500° C. But metamorphism proceeds readily at a temperature of 180° C. and for higher temperatures it would take place with still greater rapidity. The changes of dehydration and decarbonation are those requiring the absorption of heat, while the ultimate contraction of the sediments is a heat-producing operation. The final expansion of the carbon dioxide would absorb heat, but if it was able to occur only at a distance from the place of decarbonation the absorption of heat would not

enter into the problem at that point. The thermodynamics of metamorphism, however, have been discussed by Van Hise* and need not detain us. It is evident that a massive igneous intrusion would quickly impart large quantities of heat to the adjacent rocks, more than sufficient for these operations, as fast as the conductivity of the rocks could convey it.

The result would be the rapid liberation of the water and carbon dioxide as gases far above their critical temperatures. If they were retained within the original volume, the maximum pressure would be realized, and to that degree by which their rapid escape is hindered by the friction of percolation through the rocks, this maximum would be approached. Thus the internal pressures would vary directly with the rapidity of metamorphism and the frictional resistances of the channels by which the gases escape. As they gradually became dissipated, the external gravitational and lateral pressures would cause the rock mass to shrink under conditions which it is believed would effect a continuous recrystallization, accounting for the dense character and absence of infiltration.

Effects of wall-shrinkage upon the magma.—The effects of the metamorphism upon the magma depends upon a number of factors, the first to be considered being the form of the intrusion. In the case of sheets and laccoliths, the cover being the principal region undergoing metamorphism, a partial subsidence of the surface would result, following shortly after the original uplift.

On the intrusion of dikes, volcanic stocks, and batholiths with vertical walls, the contraction of the margins would result in a certain relief from lateral pressure, the direction of maximum shrinkage depending upon the ratio of the gravitational to the lateral forces. This leads to the consideration of two cases.

First: If the magma were intruded at the lowest temperature consistent with fluidity, solidification would begin as soon as the latent heat of crystallization had escaped into the walls. This quantity of heat would presumably not be sufficient to produce a wide contact zone, and the alteration and shrinkage would continue after solidification. The igneous mass could no longer freely follow the shrinking wall and a partial relief from pressure would occur which might determine lines of new intrusions or open the walls of dikes or veins already present. The original intrusions would show chilled margins and coarser-grained centers with veins or dikes parallel to their walls.

Second: If the intrusion were large and the temperature

*Metamorphism of Rocks and Rock Flowage, by C. R. Van Hise, Bull. Geol. Soc. America, vol. ix, p. 269.

sufficiently high, the rock would be coarse-grained up to the walls. The metamorphism would be practically completed before solidification began and during a period when the magma was able to act hydrostatically and transmit lateral pressures.

Under these conditions the shrinkage of the vertical walls would be largely lateral and result in a corresponding lateral expansion and vertical subsidence of the magma.

The shrinkage of both the intrusion and the metamorphic zone due to the progressive cooling after solidification had been completed, would result in the partial relief from lateral pressure and tend to mask any effects due to metamorphism alone. Thus a number of phenomena, such as the formation of pegmatite dikes and fissure veins near the margins of intrusive masses, though chiefly owing their origin to the contraction due to the crystallizing and cooling of the igneous rock, may find a minor cause in the shrinkage of the metamorphic zone, and the latter cause may be the factor which determines why at Elkhorn, Montana, aplite dikes several hundred feet wide are found localized at or near the contact between the granite and its sedimentary walls. Similar intrusions, though not on so great a scale, have been observed at other places near the margin of this batholith and have been noted in other localities and discussed by Pirsson.*

It may be readily seen that the relations of the metamorphosing walls to the igneous activities have considerable importance, but the development of the subject would be largely speculative and the facts at hand do not at present warrant carrying it to any greater degree of refinement.

Infiltrated strata.—Although it has been observed that as a rule, metasomatic infiltration of the metamorphosing strata does not take place, yet there are special instances where the evidence shows that it occurs. Two such which the writer has noted are due to strata of limestone containing considerable amounts of arenaceous and argillaceous impurities being confined between others of purer limestone. In both instances the strata are tilted and the inclination has made them favorable channels for the escape of mineralizing waters. The differential shrinkage has given them the porosity of a burned brick, and the analogy is the more appropriate, since in both cases the action is one of thermal metamorphism without sufficient pressure to result in a close texture.

The first instance occurs upon Elkhorn Mountain, at Elkhorn, Montana, at an elevation of 9000 feet above the sea, where two slabs of Madison limestones metamorphosed to

*"Complementary Rocks and Radial Dikes," this Jour., vol. l, pp. 394–399, 1895.

marbles are isolated from the adjacent sedimentaries by eruptions of andesite.* These blocks are 2000 to 3000 feet long and 50 to 150 feet thick. The lower, which is separated from the upper by an andesite sheet 60 feet in thickness, is tilted at an angle of 18° to the horizontal. Within this lower marble is a three-inch band of light-colored hornstone, whose mineral composition was estimated by the microscope as follows, indicating a loss of 35 to 40 per cent in volume.

	Per cent.
Diopside	50
Anorthite and labradorite	46
Quartz	2
Fluorite	2
	100

The quartz and fluorite are scattered over the section in branching nuclei and surrounding them the diopside assumes a considerable coarseness of crystallization. The process which has evidently gone forward here is, first, a crystallization of diopside and feldspar which has left the stratum very porous. Then quartz was deposited around the cavities, which were finally filled by fluorite brought in by gases escaping from the magma.

The second instance is the ore stratum of the Dolcoath mine,† situated a quarter of a mile northwest of the town of Elkhorn, Montana.

This is a bed of altered limestone 15 to 18 inches in thickness, dipping 55° east and carrying gold together with bismuth sulphide and telluride. An examination of thin sections of the ore-bearing stratum and also the foot wall and hanging wall, gave the following results, the figures on account of the nature of the sections being only approximate.

Ore Stratum.		Foot wall.		Hanging wall.	
Diopside	45	Diopside	30	Augite	5
Garnet	40	Garnet	10	Biotite	25
Calcite	12	Basic feldspar	60	Basic feldspar	66
Sulphides, with gold	3			Sulphides, no gold	4
	100		100		100

It is seen that even if all the calcite of the ore-bearing stratum be regarded as a primary mineral, the shrinkage in

* Elkhorn Mining District, Montana, by Walter Harvey Weed, U. S. Geol. Survey, 21st Ann. Report, p. 449.

† Loc. cit., p. 506.

the ore stratum has been somewhat greater than in either the foot or hanging wall, since the feldspars and biotite are minerals which, as shown by the alkalies present, were formed from sediments not fully hydrated or carbonated. Moreover a microscopic examination of the ore stratum shows parallel sinuous cracks due to tension, and not to shear, and now filled with calcite. Elsewhere in the section the calcite exists as a sponge, holding garnet, diopside and ore grains within it, and its secondary nature is not so clear. The ore is associated with the calcite and also with a certain coarser crystallization of the diopside.

Thus besides the physical effects of metamorphism which have been emphasized, the problem is seen to have an economic value in furnishing a guide in the search for strata impregnated with valuable minerals.

Relation to subordinate volcanic phenomena.—It is commonly accepted that in regions of hot springs, geyser, and fumarole action that the causes are to be found in the circulating underground waters coming in contact with still heated masses of igneous rocks, or in the gases escaping from solidifying magmas. While these are undoubtedly the chief factors, the nature of the sedimentary rocks may be such, that in the presence of igneous intrusions they may be undergoing metamorphism and evolving considerable quantities of gases and heated waters.

These effects would be more noticeable in certain regions than in others and particularly in western Montana, where the abundant Tertiary intrusions have frequently come in contact with great thicknesses of Algonkian and Paleozoic sediments, consisting in large part of mixed arehaceous, argillaceous and calcareous materials.

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Art. XXIV.—*An Expedition to the Maldives;* by Alexander Agassiz.

[Extract from a letter to the Editor of the Journal, dated Colombo, January 29, 1902.]

I have just returned from a trip to the Maldives, where I spent a little over a month examining the coral reefs of the group. The steamer "Amra," chartered from the British India Steam Navigation Co., proved a most serviceable vessel for our purpose. She carried enough coal and provisions for the trip, so we did not return to refit. She was commanded by Captain Wm. Pigott, R.N.R., who proved himself a most skilful navigator among the maze of atolls through which we steamed for over sixteen hundred miles. Both he and the officers of the "Amra" showed the greatest interest in the objects of the Expedition. Captain Pigott took charge of the sounding machine and superintended himself all the soundings we took (more than 80 in number); he became exceedingly skilful at this work, and several of the soundings were taken successfully under most trying circumstances. The "Amra" was equipped with a deep-sea Lucas sounding machine built for me by the Telegraph Construction and Maintenance Co. The machine differs radically from the American type of sounding machine developed by Captain Sigsbee with which I was familiar, and which I had in commission on all my former expeditions. Excellent as is the Sigsbee machine, the Lucas sounder has some advantages in its compactness, in being self-contained and practically automatic. But its greatest advantage lies in the use of malleable wire for sounding in place of the hard-drawn wire in use in American machines. This greatly simplifies the making of splices and lessens immensely the dangers of kinking while handling the wire. We had in addition a Sir William Thomson sounding machine for moderate depths in the lagoons or at our anchorages. I also placed on board a steam winch of the Bacon pattern with a drum large enough to hold 600 to 800 fathoms of wire dredging rope. This winch was used for deep sea towing down to 150 fms. and for the few hauls of the dredge we found time to take.

Dr. W. McM. Woodworth, my son Maximillan and Mr. H. B. Bigelow accompanied me as assistants. My son and Dr. Woodworth took a large number of photographs. Dr. Woodworth had general charge of the collections; they were intentionally somewhat limited, as we could not hope in the short time at our command to add much to the material obtained by Mr. J. Stanley Gardiner during his prolonged stay at the Maldives and Laccadives. Mr. Bigelow collected thirty species of

Medusae, interesting mainly for the geographical distribution of the genera represented. As might be expected, they were principally Hydroids, exclusive of the Siphonophores, Discophores and Ctenophores. The pelagic fauna was at times very rich and some of our deeper hauls were most productive. The surface hauls inside the lagoons were also frequently very rich, far more than in the lagoons of any other coral reef region I have visited. This may be accounted for from the open condition of the lagoons of the composite atolls of the Maldives: to this I shall call attention later on. No attempt was made to collect any plants, the collections of Mr. Gardiner having supplied the material for an exhaustive list of the flora of the Maldives.*

We made a fair ethnological collection, the better part of which we owe to the kindness of the Sultan of the Maldives. His Highness took great interest in our work, gave us a circular letter to the chiefs of the various atolls, and in addition sent a representative and an interpreter to accompany us on our trip. Thanks to this, we were everywhere received with the greatest cordiality. I have also to thank the agents of the British India Steam Navigation Co. at Colombo, Messrs. Bois Bros. & Co., for having carried out my instructions regarding the equipment of the "Amra." We found the steamer ready for us on our arrival at Colombo. To the Right Honorable Joseph Chamberlain I am indebted for his kindness in giving me letters to the government officials at Ceylon, and for writing to His Excellency Sir West Ridgeway in regard to our proposed visit. The Governor kindly wrote to the Sultan of the Maldives notifying him of the objects of our expedition, and also gave me letters to the Sultan, which we delivered on our arrival at Male.

We started on our explorations from Male after having, on making the atoll, obtained a glimpse of the east coast of North Male as we skirted the atoll from Mirufenfurhi to Male Island itself. This stretch of coast together with the islands near Male and the adjoining faros† of the lagoon to the northwest of Male contain all that is most characteristic of the atolls of the Maldives. A glance at the chart gave us an approximate idea of the problems to be solved in the study of the coral reefs of the group.

After examining North Male we passed to Ari, then to North and South Nilandu, crossing to Mulaku, making our way to Kolumadulu, to Haddummati, to Suvadiva, and to Addu, the southernmost atoll of the Maldives. On account of

* The Botany of the Maldive Islands, by J. C. Willis and J. Stanley Gardiner, Ann. Royal Botanic Gardens, Peradeniya, December, 1901.

† Faro is a name given by the natives to the small atolls which rise in the interior of the large lagoons or are found on their rims.

the heavy sea we were unable either on our way south or north to stop at Fua Mulaku, an island between Suvadiva and Addu, but judging from the chart and such accounts as I could obtain, it probably does not differ from similar islands in the Maldives.

On our way north we modified our course so as to visit the faces of the atolls we had not seen on our way south, and to cross the lagoons from a different direction, taking thus a bird's eye view of the atolls and islands. Our route was further daily modified according to the position of the sun, to enable us to navigate the interior of an atoll in safety, or to take photographs as we passed, without loss of time. We also examined the atolls of the eastern chain which we had not seen: Wattaru, Felidu and South Male. From Male Island we examined the western parts of North Male, which we had not visited before, passed on to Gafaru, to Kardiva, to Fadiffolu, to South Malosmadulu, to Gadu, to middle Malosmadulu and North Malosmadulu, to Miladummadulu, crossing to Makunudu and Tiladummati. We left the Maldives through one of the passages on the east face of Ihavandiffulu, the northernmost atoll of the group, after having steamed nearly sixteen hundred miles among the atolls of the Maldives.

Although the waters within the groups of atolls on the Maldives have been most carefully sounded by Captain Moresby and Lieut. Powell, yet very little is known of the depths in the channels separating them, or of the depths on the two sea faces of the great plateau upon which the atolls of the Maldives have developed.* The soundings give an excellent idea of the topography of the bottom of the lagoons of the composite atolls; their greatest depths is not much more than 40 fathoms. The depths indicate considerable variation over the bottom, and in some regions these changes in depth are very abrupt, from 8 to over 20 fathoms in short distances. The character of the bottom varies greatly according to the locality and its vicinity to gaps, to passes, to islands or islets or sand bars. In many cases the bottom is hard, swept clean by the currents, or covered with fragments coated with Nullipores, or it is covered with corallines or made up of fragments of broken corals, or of coarse or fine coral sand. On one occasion the claspers brought up a piece of Millepore cut off from a living cluster from a depth of 39 fathoms. This is an unusual depth for a reef builder, as in the Maldives the reef corals rarely extend below 17 fathoms; 12 fathoms is the usual depth I have observed.

* Mr. J. Stanley Gardiner took a number of soundings across these channels, but he has not yet given the position of his casts. See the Fauna and Geography of the Maldive and Laccadive Archipelagoes, vol. i, part i, p. 19, and Introduction to the above, pp. 10, 11. (Noticed in this number.)

There the sand lanes and patches which separate them, and which finally end in covering the bottom, usually begin.

The connection of the northern Maldives with Minikoi and the Laccadives, as well as the relation of the latter with the southwestern coast of India, is fairly well developed by existing soundings.*

A good line of soundings also runs between the Northern Maldives and South India connecting with the numerous soundings taken off the west coast of Ceylon.† On our way back to Ceylon we filled a few important gaps in this line which clearly developed the existence of a wide tongue of the ocean coming from the south with a depth of over 1,500 fms., reaching north of the 9th degree of northern latitude and separating Minikoi as well as the Maldives from the Indian Continental slope.

We did not attempt to check any of the soundings. Within the atolls they exist in sufficient number for all theoretical and practical purposes, and for a party not sufficiently numerous and not properly equipped for the most delicate surveying operations it would have been hopeless to add any exact information to that already existing. Our soundings were limited to filling gaps in the existing information, such as taking the depths of the channels separating the groups of atolls as well as developing the slopes of the eastern and western faces of the Maldivian plateau.

Our soundings showed a greatest depth of 251 fms. in the center of Gallandu Channel, which separates Ihavandiffulu from Tiladummati; 769 fms. in the center of the channel between Miladummadulu and Fadiffolu. The Admiralty Charts indicate depths varying between 125 and 135 fms. in Moresby Channel between north and middle Malosmadulu, and depths varying between 100 and 140 fms. in the channel between the latter and South Malosmadulu. We found 302 fathoms between Goidu (Horsburgh atoll) and South Malosmadulu. In the center of Kardiva Channel on the two sides of Kardiva island we obtained 312 and 298 fms. with 372 fms. one and a half miles south of Fadiffolu atoll. One hundred fathoms was obtained in the center of the channel between Gafaru and North Male. Between North and South Male in the center of Wadu Channel we got a depth of 260 fathoms. In the center of Fulidu Channel separating South Male from Felidu atoll we found 374 fathoms. In the channel north of Wattaru Reef we found 283 fathoms; in Wattaru channel between Wattaru reefs and Mulaku atoll 253 fathoms, and between Mulaku and Kolomadulu the depth in the center of the channel

* See B. A. Charts Nos. 2737 and 2738.
† See H. O. Chart No. 1591.

increased to 649 fms. Returning now to the groups of the western chain of atolls we found 231 fathoms in the Ariyaddu Channel between Ari and North Nilandu. The charts indicate 200 fathoms in the center of the channel between North and South Nilandu and between it and Kolumadulu, the northernmost of the southern single chain of atolls, we found 251 fathoms in the center of the channel.

In the wider channels separating the atolls of the southern single chain the depths become much greater. In the center of the Veimandu Channel which separates Kolumadulu and Haddummati, the depth had increased to 1,118 fms., and half way between it and Suvadiva we found a depth of 1,130 fms. In the wide channel between Suvadiva and Addu we found 1,292 fms. a little to the north of Fua Mulaku and 1,048 fms. between it and Addu. At a distance of four and a half miles to the south of Addu we ran into 718 fms. Owing to the rough weather we were obliged to discontinue our southern line, which I hoped to connect with the single sounding of 2,500 fms. between Addu and Chagos indicated on the Admiralty Charts. I believe that the "Valdiva" also made a few soundings between Ceylon and Suvadiva as well as south of Addu on her way to Diego Garcia; unfortunately I have not her list of soundings at hand, and am not able to state what light they throw on the depths separating Addu, the southernmost of the Maldives from the Chagos Archipelago.

The bottom samples of the deeper soundings were interesting as showing the existence of Globigerinae in great quantities at a comparatively short distance from the shallower parts of the Maldive plateau. Though we did not find Globigerinae in our tows except on one occasion, Globigerinae were frequently so abundant on the bottom as to form what might be called Globigerinae sand. In somewhat shallower soundings and nearer the atolls Pteropod shells were common, and these we collected in numbers in nearly all our tows made on the outer faces of the Archipelago. In two of the soundings in the channels between the composite atolls we brought up small manganese nodules existing much in the condition in which they were dredged by the "Blake" in the Straits of Florida.

As regards the slopes of the eastern and western faces of the Maldive plateau our soundings are of considerable importance. The soundings of Ihavandiffulu found on the charts indicate a depth of over 1000 fms. off the southwestern face at a distance of nearly twelve miles. Off the northeastern face nearly the same depth is reached in less than six miles. To the east of the northernmost point of Tiladummati, at a distance of seven miles, 781 fms. is indicated on the chart, and about 13 miles to the eastward we ran into 1,460 fms. In the center of

the channel separating the northern extremity of Makunudu and the northwestern extremity of Miladummadulu we obtained 792 fms. Eight miles west of the southern part of North Malosmadulu the depth was 1,247 fms. Off the southwestern face of Ari we ran into 1,499 fms. at a distance of eight miles. The only line we ran into deep water off the east face of the Maldives was off the center of the east face of South Male, where we found 1,270 fms. at a distance of twelve miles from Guru Island. These soundings indicate a comparatively steeper slope off the west face of the Maldive plateau than off the eastern face.

As regards the great wide basin which separates the chain of the eastern group of atolls from the western one, beginning at the north we find as great a depth as 513 fms. in the center of the northern part of the channel separating Miladummadulu and North Malosmadulu. In the line from Fadiffolu to South Malosmadulu we find 519 fms. within a mile and a half of the former, with not more than 364 fms. in the center of the channel. In the center of the channel between Gafaru and Goidu the greatest depth is 258 fms. A short line run west of North Male atoll, somewhat south of the center of the west face, indicates, from the depth of 186 fms. obtained at a distance of five miles, that the plateau of that part of the western face is quite shallow, and that Toddu and Ross atolls (Rasdu) are on its western rim. This is corroborated by the soundings on the charts off these atolls to the north of Ari, somewhat to the west and south of our line. In the center of the channel separating Ari and South Male we found 318 fms., while we obtained 194 fms. near the center of the line between South Nilandu and Mulaku, with a deepest sounding of 205 fms. three miles off the west face of Mulaku. I should add that the bottom of all the channels separating the composite atolls appears to be quite flat, the soundings drop rapidly, and generally at a distance of a mile and a half from either face they reach a depth but little inferior to the greatest depth in the center of the channels.

The greatest depths thus far obtained in the channels separating Minikoi from the northern Maldives (1,179 fms.) and the former from the Laccadives (1,197 fms.) are about those which separate the Southern Maldives from one another and from the central part of the group.

It is interesting to note that both Minikoi and the Laccadives as well as the Southern and Northern Maldive atolls and some others to which I shall refer later have none of the characteristics of what has been called the composite Maldivian atoll, but on the contrary resemble such Pacific atolls as characterize mainly the Ellis and Gilbert groups.

A mere glance at the Admiralty Charts of the Maldives* can-

* B. A. Charts Nos 66*a*, *b*, *c*.

not fail to show at a glance how very different in structure are Makumudu, Gafuru, Kardiva, Goidu, Rasdu, Toddu, Wattaru, Fua Mulaku and Addu from such groups of atolls as North and South Male, Ari, North and South Nilandu, Felidu, the Malosmadulu atolls, of Miladummadulu and its northern extension Tiladummati, which might be called the Maldivian group of atolls par excellence; both to be contrasted again to such atolls or groups of atolls as Fadiffolu, Felidu and Mulaku, which have as it were combinations or modifications characteristic of the Maldivian atolls with features common to a great number of Pacific atolls. And finally we come to a third class of atolls like Kolomadulu, Haddummati and Suvadiva, which remind us of some of the larger atolls of the Pacific in the Marshall, Ellis and Gilbert Islands or Caroline Islands; atolls noted for the absence of shoals and of islands in the lagoons, while the typical grouping of the small Maldivian atolls along the 40 to 30 fathom line of the great Maldivian plateau forms an agglomeration of small atolls along that belt resembling the great reef flats of the Pacific atolls, but which have grown up as distinct parts and are separated by deep channels. These small atolls vary in size from a couple of hundred feet in diameter to atolls of seven miles in length. While it is true that in such clusters of atolls as those of North and South Male, of Ari, of the Malosmadulu atolls and of others, their arrangement is such as to form well-defined well-marked rims, reminding us of the rims formed by great reef flats such as are common in the Pacific, yet the structure of such groups of atolls as Miladummadulu and its Tiladummati extension misnamed as atoll gives us the key to a rational explanation of the formation of the atolls and groups of atolls in the Maldives.

The two atolls I have just named are not atolls in any sense of the word. They are so ill-defined that their division on the chart for political purposes is marked by a mere dotted line. In fact they are a great number of small atolls often separated by considerable distances as much as five to ten miles which have gradually grown up on that part of the Maldivian plateau from depths of 25 to 30 fathoms, and where they can be seen in all possible stages of growth. We examined them in detail at several points in the Maldives. Their mode of growth and the great variety of conditions under which they exist is well seen in North Male. There we see many of the future atolls existing as flats or bars or mere rings which do not rise more than five or six fathoms from the top of the plateau; others which vary in depth from the surface from three to five or seven fathoms. Others again which form rings or bars just awash or with two to three feet over the rim, and finally rings partially awash only with sand banks projecting a foot or so

above the surface. The shape of these rings or bars or flats is not necessarily circular, it varies greatly and is indirectly controlled by the topography of the bottom. Some of these faros are elliptical, pear-shaped, or crescent-shaped, varying greatly in outline and dimensions on the outer lines of the composite atolls. In some of the atolls the lagoons of the smaller atolls have been formed by the growth of coral patches or lines of corals rising at a short distance lagoonward, parallel with the outer reef flat. These patches become joined and form thus elongated lagoons or a number of secondary lagoons on the outer reef flats.

There is no evidence that these small atolls are the result of the splitting or breaking up of what was formerly a larger atoll, nor that adjoining atolls or reef flats have become united or coalesced except where the passages separating them have been of very moderate depths. No such changes are indicated anywhere from a comparison of the conditions as marked on the chart of 70 years ago and those existing to-day.

The outer slopes of these rings are covered with corals growing with great luxuriance from the edge or even far on the flats of the ring to a depth of from eight to twelve or fifteen fathoms. The superb growth of corals found in all the so-called lagoons of the Maldives is in marked contrast with the scanty growth of corals in the lagoons of the atolls of the Pacific. It seems we have a simple explanation of this in the fact that the rim of these so-called atolls in the Maldives is full of wide and deep passages. In fact, the extent of the passes is generally much larger than the space occupied by the small atolls (the atollons). As soon as the flats of the rings have reached the surface, either wholly or in part, sand bars begin to form, and these develop rapidly into islets and finally large islands more or less covered with scrub vegetation and bushes. These rings or faros either retain a central lagoon or it becomes partly or wholly filled up. In the former case they appear as small atolls with islands or islets on the reef flats; in the next stage there is only a smaller lagoon on the lee face of a larger island, or else the island has grown to occupy the whole flat of the faro with only very narrow flats on the lagoons faces of which corals grow. These larger islands are often covered with fine vegetation, large trees occupying the space inside of the outer belt of bushes growing close to the beach. The greater number of the many islands which dot the so-called lagoons of the Maldives have been formed in the manner described, and it is comparatively easy to trace the progress of development in all the stages intermediate between a mere ring not yet rising to the surface and an island with its rich vegetation such as we find either in the lagoons or on the outer edge of the Maldivian composite atoll.

The small atolls which form the outer rim of the composite atolls owe their existence to the same causes, and their development can be easily traced from a mere ring which has risen to the surface having more or less extensive flats on which islands or islets, or sand bars have been thrown up. The sea-reef flats of these outer lines of atolls are usually wider than those of the lee-face, and naturally so.

The increase in size of the islands of the outer line of atolls we find goes on much as we have observed it in the Gilbert, Ellis, Marshall and Paumotu Islands. Small islets or islands on the same reef flats are gradually united by the formation of sand spits on the lee-face of the islands, thus forming bays on the sea-face of an atoll; the spits gradually approach, become connected, and the filling up of the bay from the sea-face unites adjacent islands, their former disconnected state being indicated merely by a difference in the growth of the vegetation, a distinction which gradually disappears with years. The bay may be formed also on the lee-side by the throwing up on the sea-face of a bar on the edge of the reef flat between separate islands, and the bay may then be filled up both from the lee and weather side and thus unite separate islands or sand bars.

The existence of lagoons completely shut off from the sea in some of the atolls of the northern part of the Maldives is readily explained by their mode of formation; this can be traced in all its stages from the time the atoll consists of a crescent-shaped island occupying only a portion of the reef flat of the ring, the reef flat of the rest of the ring still enclosing a comparatively deep lagoon sometimes 6 to 7 fms. The island throws out spits from the horns of the crescent until there is only a narrow pass left between them, and finally this gap is closed by a sand or shingle beach and we have the ideal atoll, a closed ring of land enclosing a deep lagoon, which exists so rarely but is always the atoll to which one refers when discussing the coral reef question. These phenomena are well illustrated in the long line of crescent-shaped atolls occurring on the east side of Miladummadulu from Nallandu south as far as Bomasdu. Such a change from an open crescentic island flanked by a lagoon to a closed land rim surrounding a land rim may take place with considerable rapidity. Rodularmandu is represented on the chart as an open crescent-shaped island: we found it, 70 years later, á closed land ring completely surrounding a small lagoon with a depth of two fathoms. Other islands on the same reef flats have greatly increased in size by the extension of sand spits over the shallow reef flats connecting them, and it is easy to trace the amount of this growth and its comparative age by the length of these sand spits or by the quality of the vegetation on the ridge connecting them. This is well shown on such islands as Eddufaru, Milandu and many others on the east face

of the Miladummadulu bank, especially near the northern extremity of the plateau where many of the atolls, such as Hamimadu, Filadu, Kelai and others are fully as large as some of the best known atolls in the Pacific.

The formation of fresh water or brackish sinks edged with mangroves* in some of the atolls can be traced to the same process which has formed the enclosed lagoons such as we have just described. They occur on Kendikolu, Ekasdu, Nallandu, Maddelu and Filadu. The sinks differ from the lagoons only in being shallow, having been cut off by spits and bars extending across portions of the adjacent reef flats covered only by water of a couple of feet or more in depth, while the enclosed lagoons were cut off from lagoons of atolls of considerable depth, six to seven fathoms or more. What has been written above seems to me to point to the uselessness of our present definition of atolls. There is every possible gradation between a curved open crescent-shaped bank of greater or less size and an absolutely closed ring of land surrounding a lagoon without direct communication with the sea. The evidence of a great number of atolls scattered on an extensive bank or plateau like that of Tiladummati and Miladummadulu shows that reef corals will grow upon any foundation where they find the proper depth, and that local conditions will determine their existence as fringing reefs, barrier reefs or atolls. In fact, in the Maldives, reefs that once formed an atoll may in time, when the atoll is changed into an island, become fringing reefs, a transformation which is quite common both on the outer lines of islands or on islands in the interior of the smaller plateau. The so-called composite atolls of the Maldives are merely elevations upon the greater Maldive plateau which have given to the reef-building corals a base at the proper depth from which they have risen to the surface. In such smaller plateaus as North Male, Ari and others, there is found on the secondary plateaus in their turn a number of bases on which the atolls have grown. In the central and most of the northern plateaus the conditions of exposure to oceanic currents is such that an immense body of water is constantly flowing across the plateau during both the northeast and the southwest monsoons. Where the plateaus are smaller or not as open to the flow of currents as in such atolls as Addu, Kardiaa, Goidu, Gaffaru, Wattara, Makunudu, and others we have only a single atoll developed. And again in such plateaus as these upon which Kolumadulu, Haddummati and Suvadiva have developed, the conditions are oceanic (if we might call them so), more similar to those we have in the widely separated atolls of the Ellis, Gilbert or Marshall islands. At the same

* Messrs. Gardiner and Willis have already called attention to the scarcity of mangroves on the Maldives.

time, the lagoons of these atolls are far less subject to oceanic circulation than those of the northern plateaus, and thus we find fewer banks or islands in the lagoons and only here and there a trace of those remarkable rings which are so characteristic a feature in Maldivian coral reef scenery. Certainly I have seen nothing so striking in my experience of coral reefs as these rings with a light-colored rim standing out from the deep blue water surrounding them like ghosts of an atoll, which had sunk, and enclosing a lighter blue or emerald colored lagoon indicative of its depth below the surface.

The conditions existing at the Maldives is repeated to a certain extent on the Yucatan Plateau where the Alacran reef—a regular atoll—rises from the plateau at a depth of about 30 fathoms. It is true that it is the only atoll on this extensive plateau. But there are also other irregularly-shaped patches of coral reefs. The absence of atolls may be traced to the fact that the plateau is not within the area of such regular trades as are the northeast and southwest monsoons in the region of the Maldives.

The strength of the prevailing winds in the Maldives has greatly influenced many of the characteristic features of its atolls. The effect of the southwest and of the northeast monsoons cannot be compared to that of the trades in the Pacific. We have nothing in the Maldives corresponding to the incessant breakers of the huge rollers which pound upon the reef flats of the Paumotus and of the atolls and barrier reefs of the Central and Western Pacific. The boulders thrown upon the reef flats are mere pigmies compared to the gigantic masses moved on some of the reef flats of the Pacific reefs. The boulder belts seem like a newly-macadamized road as compared to the quarry blocks which often line miles of the beaches of the Pacific atolls. But the same forces are at work in the Maldives only on a diminutive scale even during the prevalence of the southwest monsoon. The beaches are as a whole remarkably steep, both sand and shingle; they rarely rise to more than five or six feet, though in some of the northern atolls they are fully 12 feet high. Mr. Gardiner informs me he has seen dunes rising to 28 or 30 feet in height. Many of the islands have sinks occupying the central portion of the island; they have all been formed by the enclosure within the outer and higher sand or shingle beaches of the interior part of the island. The beaches have been gradually raised until they met the belt of vegetation which prevented the sand from raising the interior part of the island.

Wherever reef-rock was examined I found it without exception of the most modern character, a few exposures as horses on the beaches and on the reef flats would seem to indicate a slight elevation of the Maldives. The horses or outliers were deeply undercut, pitted and honeycombed, showing that they

were remnants of reef flats which once rose to a height of from three to four feet greater than they do at the present day.

If the existing conditions at the Maldives have been brought about by subsidence, it is strange we should not find anywhere on this extensive plateau, especially all the way from the northernmost atolls as far as Kolomadulu, some trace, some outlier or some central projecting rock indicating the nature of the rocks composing the underlying plateau forming the base upon which the innumerable atolls of the Maldives have been formed. The conditions are in many ways similar to those of the Lau Islands on the eastern plateau of Fiji. But there the elevation has been considerable (to a height of 1,000 feet), and everywhere indications are found of the character and age of the underlying strata. A similar condition exists in the Paumotus, where some of the tertiary elevated reefs attain an elevation of about 300 feet. At the Maldives there is, however, only evidence of a very slight elevation.

Our explorations were immensely facilitated from the existence of the admirable charts published by the Admiralty of the Survey of the Maldives by Captain Moresby and Lieut. Powell from 1834 to 1836. The accuracy of these charts is something wonderful when we remember the conditions under which the surveys were made nearly 70 years ago, with sailing vessels and row boats. In our extensive and intricate navigation among the Maldives we were guided absolutely by these charts and never found them in error. Of course some minor changes have occurred on the reef flats, such as the disappearance of an islet, or of a bank, or the addition of a sand bar and the junction of adjoining islands or islets on the same reef flats. Otherwise the charts stand to-day as they did 70 years ago, a monument to the unsurpassed skill of the surveyors of those days. It was a simple task to pick out one's work in each atoll by an examination of the chart, and thus much time was saved.

In addition to the information to be derived from the charts, Mr. J. Stanley Gardiner was kind enough on two occasions, after his return from the Maldives, to give me valuable details regarding many interesting localities. I can only close by expressing my admiration for the amount of work Mr. Gardiner was able to accomplish with the facilities at his command, and for the pluck and energy displayed by him and his companion, Mr. Cooper, in meeting, in native boats, the winds and currents which impeded their progress at every point, to say nothing of the constant discomforts to which they were subjected during their stay in the Maldives.

As soon as the necessary charts can be made, I hope to publish a preliminary report of our exploration, leaving the final report to appear whenever the illustrations and photographs taken on the trip can be prepared.

ART. XXV.—*The Flower-like Distortion of the Coronas due to Graded Cloudy Condensation;* by C. BARUS.

1. RECENTLY I described* a series of results obtained most satisfactorily with benzol† vapor, in which the coronas met with are not closed and annular, but of a variety of patterns from oval, with the long axis vertical to the symmetrically open doubly inflected types (lyre-shaped or basin-shaped), running continuously into horizontal strata as the limiting case. These distortions are due to the non-uniform distribution of nuclei as to size, the largest having sunk deepest and the finer nuclei floating uppermost, in virtue of the precipitation mechanism. When supersaturation is produced by adiabatically cooling the benzol vapor, the condensation begins at the lower strata and then passes upward as exhaustion proceeds and higher degrees of supersaturation are reached. The evolution of coronas is peculiar in this case, and reminds one of a person throwing out his arms laterally and upward until his hands strike above his head. The sweep of coronal streamers is outward and upward symmetrically with respect to the vertical plane through the source of light. If the gradation is not too rapid, they eventually coalesce above it.

The droplets produced are finer above than below; but it does not follow that there are more particles in the upper layers. The reverse will naturally be assumed. The lower particles being larger have first received the condensation as already suggested, and have thus grown biggest, as the opportunities for growth came earliest and lasted longest.

2. It is my purpose in this paper to work out the shape of the *loci of like color* when the nucleation is not uniform as to size or number. The distributions arise from the subsidence of loaded nuclei; they are, therefore, horizontally stratified.

In figure 1, let o be the distant point source of light into which the coronas would shrink annularly and symmetrically from without inward, to a limit in a normal case. Let ϕ be

* Science, xv, pp. 175–178, 1902.

† The nuclei do not originate in the benzol itself as I first supposed, but are due (as I have since found) to the diffusion of a horizontal couche of nuclei, brooding immediately over the surface of the liquid. For this reason this residual layer is liable to escape detection on purifying the air of nuclei by exhaustion. For my purposes it is a matter of little consequence whence these residual nuclei come, and I have, therefore, not given much attention to it. The occurrence of the diffusion is the essential feature. In carbon disulphide, however, the nuclei certainly arise out of the liquid, though it is not improbable that even here they are a foreign sulphurous product. Saturation is soon reached at an enormously low but permanent vapor tension. The question will soon be discussed elsewhere.

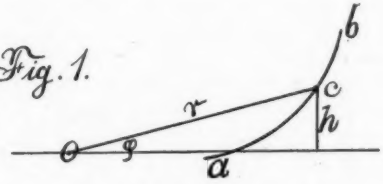
the angle between the horizontal through o and the radius vector, r, to a line of uniform color, ab, in the distorted corona, and let h be the height of the extremity, c, of the radius vector above the datum line through o. If R be the distance of r from the eye of the observer, $2r/R = s/R$ is the angular aperture of the corona.

Let δ be the diameter of the particles at the level passing through c. Then if δ_0 and s_0/R be the corresponding quantities (diameter and aperture) of particles in the datum level,

$$\delta s = \delta_0 s_0 = \cdot 00144, \qquad (1)$$

the number being found by experiment for normal coronas. Hence $r \cdot d\delta + \delta \cdot dr = 0$ (2) where $r = s/2$. Again if the angle ϕ increases counter-clockwise by $d\phi$,

$$r \cdot d\phi \cos \phi + dr \cdot \sin \phi = dh. \qquad (3)$$



Let $d\delta = a dh$ (4) so that the diameter of the water particles is supposed to decrease (a being negative) uniformly upward. Other laws of distribution would merely complicate the problem without conducing to the present purposes, seeing that the observed facts will be sufficiently interpreted by equation (4). Combining (4), (3), (2),

$$r \cdot \cos \phi d\phi + \sin \phi dr = -(\delta/a)\,(dr/r) = -\cdot 00072\, dr/ar^2,$$
by equation (1) (5)

Put $A = \cdot 00072 / a$ and integrate (5) whence $\sin \phi = C/r + A/r^2$. To determine C, equation (1) is available, since for $\phi = 0$, $r = r_0$. Therefore

$$\sin \phi = -(4A/s)\,(1/s_0 - 1/s).$$

To construct these coronas distorted in consequence of the linear distribution of size of particles, it will generally be more convenient to express s in terms of ϕ, so that finally,

$$s = -(2A/s_0 \sin \phi)\,(1 - \sqrt{1 + s_0^2 \sin \phi / A}) =$$
$$-(\delta_0/a \sin \phi)\,(1 - \sqrt{1 + 2as_0 \sin \phi/\delta_0}). \qquad (6)$$

With this equation the following table has been computed (a is for convenience entered positively). To have an average case at the datum level, put $\delta_0 = \cdot 001^{cm}$, as the diameter of

TABLE. — Flower-like coronas due to graded condensation. $s = -(2A/s_0 \sin\phi)(1-\sqrt{1+(s^2_0/A)\sin\phi})$; $\delta = \delta_0 - ah$; $A = -\cdot00144/2a$; $\delta_0 = \cdot001^{cm}$; $\delta_0 s_0 = \cdot00144$; $s_0 = 1\cdot44^{cm}$; $s_m = 2\cdot88^{cm}$.

ϕ	(1) s cm.	(2) s cm.	(2′) s cm.	(3) s cm.	(4) s cm.	(5) s cm.	ϕ
−90°	1·36	1·35	1·19	1·12	·97	·58	−90°
−67·5	1·38	1·35	1·20	1·14	·99	·60	−67·5
−45	1·41	1·38	1·24	1·19	1·05	·66	−45
−22·5	1·43	1·40	1·32	1·28	1·18	·80	−22·5
±0	1·44	1·44	1·44	1·44	1·44	1·44	±0
+22·5	1·46	1·48	1·61	1·72	---		+22·5
45	1·47	1·52	1·86	---	---		45
67·5	1·49	1·55	2·25	---	---		67·5
90	1·50	1·56	2·88	---	---		90

$a =$	·00005	·00010	·00035	·00050	·00100	·00500
$A =$	−14·4	−7·2	−2·07	−1·44	−·72	−·144
$2A/s_0 = \delta_0/a =$	−20	−10	−2·87	−2	−1	−·2
$s^3_0/A = \frac{2s_0 a}{\delta_0} =$	−·144	−·288	−1·00	−1·44	−2·88	−14·4
$\phi_m =$	---	---	90	43·9	20·3	3·9

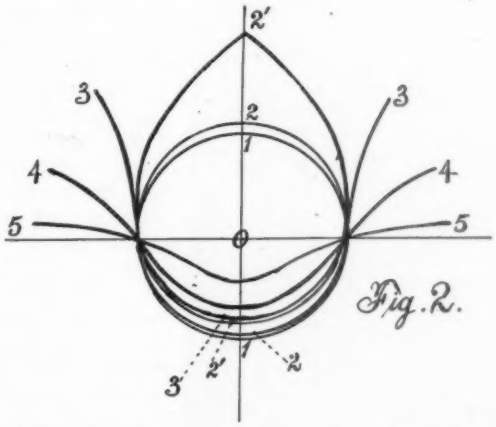


Fig. 2.

particle. The values of s are given for 9 values of ϕ and for 6 values of a; viz., $a = \cdot00005$, $\cdot0001$, $\cdot00035$, $\cdot0005$, $\cdot001$, or for $a/\delta_0 = \cdot05$, $\cdot1$, $\cdot35$, $\cdot5$, $1\cdot0$, as decrements of diameter per linear centimeter of level above h_0.

The curves showing the loci of uniform color for these different conditions are constructed in the chart and numbered 1–5 in succession. No. 1 is still very nearly circular, while

No. 2 is more oval, the members having risen above No. 1. Both curves are closed. No. 2′ is the interesting transitional case between closed and open curves concerning which presently. No. 3 is already quite open and bell-shaped; No. 4 more so; No. 5 is basin-shaped, and succeeding curves would more and more nearly approach the horizontal line through the source. Naturally all curves pass through the same two points in this line.

Moreover equation (6) shows that s becomes imaginary when $1 < (s^2_0/A) \sin \phi$ since A is negative. The final values of s and ϕ are thus given by $\sin \phi_m = -A/s^2_0$, so that on reduction $s_m = 2s_0 = 2{\cdot}88$. These data are also given in the table. It is further apparent that the corona will just begin to open on top when $1 = -s^2_0/A$, or $\sin \phi = 1$. Since $A = -{\cdot}00072/a$ and $s_0 = 1{\cdot}44$ the gradient $a = {\cdot}0035$. This is the curve No. 2′ between the conditions of Nos. 2 and 3. In all these cases the equation given strikingly interprets the opening of a harebell or what would be called campanulate efflorescence in botany.

I may add in conclusion that all the types of curves given are continually and repeatedly met with in working with volatile liquids, among which I have now examined gasoline, benzine, benzol, and carbon disulphide, at length. The law of distribution reproduces the cases as nearly as they can be tested in the fleeting coronas, though the real law is not liable to be linear and will have to be specially worked out.

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Art. XXVI.—*Varying degrees of Actinism of the X-Rays;* by John O. Heinze, Jr.

One is often disappointed, in taking X-ray photographs, at not obtaining good impressions even when the fluoroscope shows a brilliant effect. It, therefore, seems probable that the rays which are most active in producing fluorescence are not necessarily those which act most vigorously on the photographic plate.

In order to test this hypothesis I took a number of observations in the following manner: Having at my command a powerful coil the discharges of which could be regulated with great exactness, and also having a large selection of the most approved X-ray tubes which had been exhausted under my personal superintendence and the behavior of which had been carefully studied, I made a number of exposures and noted at the same time the appearance of the object in the fluoroscope. Fig. 1 shows the results obtained.

1

The exposures were made through a slot in a thick lead plate placed between the tube and the negative. The latter was moved along one stop for each minute of exposure; and the intensity of the secondary current was varied with each exposure, starting at one minute with the weakest current and ending at the eighth minute with the strongest current. It will be seen that at the fifth minute the greatest actinic effect was obtained and at eight the most brilliant screen and poorest actinic light. The coil which was used in this experiment is one constructed by me

and gives very constant results. It was actuated by a liquid break which enabled me to regulate the current in a manner which would be impossible with a mechanical break. The performance of the coil bears out Lord Rayleigh's contention that the electrostatic capacity of the coil between the primary and the secondary is an important feature in the performance of a coil and that a condenser in the primary is often detrimental. My coil has no condenser and the break is practically instantaneous. There is an enormous rush of current through the primary at the maximum output.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Separation of Hydrochloric and Hydrocyanic Acids.*—In order to determine small quantities of chlorides in alkaline cyanides, Richards and Singer dissolve about 1·25^{g} of the substance in 400^{cc} of water, add 5^{cc} of sulphuric acid to the solution, and boil for two hours in a retort, the neck of which slants upward, with replacement of the water lost by evaporation so that the volume does not become less than 300^{cc}. In this way all the hydrocyanic acid escapes with the steam, while there is no loss of hydrochloric acid, even after boiling for more than eleven hours. The residual hydrochloric acid is readily determined by the usual method of precipitation with silver nitrate. The authors explain the difference in behavior of the hydrocyanic and hydrochloric acids on the ground that the former is but slightly ionized in solution while the latter is very thoroughly ionized in dilute solutions. Ions have little or no tendency to leave an aqueous solution with steam, while the unionized hydrocyanic acid displays its usual volatility when its solution is boiled. The time of boiling which has been mentioned, two hours, while sufficient to remove the hydrocyanic acid from a small quantity of hydrochloric acid, is insufficient when larger quantities of the latter, for instance amounts corresponding to about one-tenth of a gram of potassium chloride, are present. In this case boiling for eight or nine hours appears to be necessary. From this interesting result the conclusion is drawn that the chloride ion must tend to form a complex with hydrocyanic acid, and that this complex seems to be entirely broken up by prolonged boiling without the loss of hydrochloric acid.—*Amer. Chem. Jour.*, xxvii, 205. H. L. W.

2. *Volumetric Determination of Copper, Antimony, Iron, etc., by Means of Stannous Chloride.*—In 1878 Weil described a method for determining these substances. The titration, according to the original plan, is carried out in a flask in the presence of very strong hydrochloric acid. During the operation the liquid is kept boiling so that air cannot enter the flask and cause an error by its oxidizing action. The end of the reaction in the cases of copper and iron is distinctly marked in strong acid solution by the disappearance of color. When antimonic acid is present with copper it is reduced with the latter by stannous chloride, but after the resulting liquid has been exposed to the air for a few hours the cuprous chloride is oxidized to cupric chloride while the antimonious chloride remains unchanged, so that the former can be determined by a repetition of the operation, and the amount of antimony present can be calculated. When ferric salts are present with copper they are also reduced by stannic chloride, but the copper can be removed by means of

metallic zinc, and after oxidation with potassium permanganate and the removal of chlorine by boiling, the iron can be determined by the stannous chloride titration. Weil now calls attention to an improvement in his process by which the disagreeable vapors of boiling hydrochloric acid may be dispensed with. He adds to 10^{cc} of the liquid to be analyzed 30^{cc} of hydrochloric acid and some pieces of white marble in a flask, and then runs in stannous chloride at the ordinary temperature. The carbon dioxide fills the flask and keeps out the air.—*Comptes Rendus*, cxxxiv, 115. H. L. W.

3. *Comparison of the Properties of Hydrogen Selenide with those of Hydrogen Sulphide.*—A careful study of the physical properties of hydrogen selenide has been made by DE FORCAND and FONZES-DIACON. Several constants relating to hydrogen sulphide which were previously somewhat doubtful have also been determined in order that a comparison could be made. The results are given in the following table:

	H_2S	H_2Se
T, boiling-point (abs.)	211·4°	231°
T_c, critical temperature (abs.)	373·2	410
$\frac{T}{T_c}$	·566	·564
P_c, critical pressure, atmospheres	92·	91·
T′, melting-point (abs.)	187·	209
D, density of liquid at T	·86	2·12
$\frac{PM}{D}$, molecular volume of liqnid	39·53	38·11
L, heat of volatilization (calories)	4230	4740
$\frac{L}{T}$, Trouton's relation	20·01	20·52
C, heat of formation of hydrate (calories)	16340	16820
t, temperature at which the hydrate has a tension of 760^{mm} (abs.)	273·35	281·
S, solubility at + 4° (volumes)	4·04	3·77
" + 9·65 "	3·60	3·43
" +13·2 "	3·35	3·31
" +22·5 "	2·75	2·70

It is evident that the two gases show a remarkable analogy, but their properties are very different from those of water, as is shown by the following relations of the latter:

$$\frac{PM}{D} = 18{\cdot}82, \quad \frac{L}{T} = 25{\cdot}87, \quad \frac{T}{T_c} = {\cdot}585, \quad P_c = 200 \text{ atm.}$$

—*Comptes Rendus*, cxxxiv, 281. H. L. W.

4. *Radio-active Thorium.*—HOFMANN and ZERBAN have found that thorium preparations from bröggerite, while showing much activity in acting upon the photographic plate and upon the electroscope when freshly prepared, lose this power almost or

quite completely after being preserved in closed vessels for a few months. They believe, therefore, that the radio-activity of thorium compounds is not inherent but induced by the uranium contained in the minerals from which they are extracted. This view is confirmed by the fact that thorium from monazite sand containing no uranium is entirely inactive, while preparations from bröggerite, cleveite, samarskite, thorite and orangite are most active in the cases where the larger quantities of uranium are present.—*Berichte*, xxxv, 531. H. L. W.

5. *Lithium Antimonide.*—It has been found by LEBEAU that antimony and lithium combine with violence when they are heated together, but that the heat thus produced prevents the preparation of a definite compound. However, upon electrolyzing a mixture of the chlorides of potassium and lithium with a cathode of antimony, a definite crystalline compound corresponding to the formula Li_3Sb is produced. The same compound can be prepared by the action of lithium dissolved in liquefied ammonia upon metallic antimony. It is somewhat soluble in the ammonia, giving the compound Li_3SbNH_3 upon evaporation.—*Comptes Rendus*, cxxxiv, 231, 284. H. L. W.

6. *A New Synthesis of Formic Acid.*—MOISSAN has found that the hydrides of potassium and sodium take fire at ordinary temperatures in an atmosphere of carbon dioxide. If the temperature produced by the reaction is not allowed to rise too high so as to destroy the product, it is found that a formate is produced. In the case of potassium hydride the reaction is as follows:

$$CO_2 + KH = HCOOK.$$

It was found also that carbon monoxide is slowly attacked by potassium hydride with the formation of formate and carbon according to the equation,

$$2CO + KH = HCOOK + C.$$

—*Comptes Rendus*, cxxxiv, 263. H. L. W.

7. *Elements of Physical Chemistry;* by HARRY C. JONES. 8vo, pp. 549. New York, 1902 (The Macmillan Co.).—This volume is designed especially as a text-book for advanced students of chemistry and physics. The author makes the point in the introduction that we are too much inclined at present to treat physical chemistry as a subject which has originated in the last fifteen years. So he has devoted much space to the work of the earlier investigators—work which was really the foundation of much that has developed in the last few years. At the same time, the modern theories and their applications are taken up very thoroughly and very well.

From the standpoint of the teacher, the treatment seems occasionally a little too mathematical, for the average student in chemistry is certainly not well grounded in higher mathematics. For instance, the relation between the specific heats of gases at constant pressure and at constant volume can be explained equally well without the use of calculus. H. W. F.

8. *Velocity of Sound in Air and in different Vapors with Ordinary and High Temperatures.*—This is a very complete study of the subject by E. H. STEVENS. He employed the apparatus described by Quincke in Wied. Ann., lxiii, p. 66, 1898, which he found to be the most accurate for the purpose that has been devised. In general it consists of two cylinders. The wider, called the interference cylinder, is closed at one end and holds the gas or vapor. In the neighborhood of the mouth of the tube is the resonator of a tuning fork. The wave, spreading out from this, passes into the tube, and is reflected from the closed end, forming with the direct wave a standing wave. The wide cylinder contains also a much narrower tube, open at both ends. The end projecting from the wider tube is provided with a rubber attachment which one applies to one ear, while the other is suitably closed. One pushes this narrow tube to and fro in the wide cylinder until one finds maxima and minima. The author gives the following table of the velocity of sound and the ratio of specific heats at constant volume and constant pressure.

Substance.	$t°$.	Vm/sec.	k.
Dry air	0°	331·32	1·4006
"	100	386·5	1·3993
"	950	686·0	1·34
Ether	99·7	212·6	1·112
Methyl alcohol	99·7	350·3	1·256
Ether alcohol	99·8	272·8	1·134
Bisulphide carbon	99·7	223·2	1·234
Benzol	99·7	205·0	1·105
Chloroform	99·8	171·4	1·150
Acetic acid	136·5	....	1·147
Iodine	185·5	140·0	1·303

—*Ann. der Physik*, No. 2, 1902, pp. 285–320. J. T.

9. *Chemical Action of Cathode Rays.*—G. C. SCHMIDT controverts the hypothesis of Goldstein (Wied. Ann., ii, p. 832, 1880) that the chemical action of the cathode rays is due to a very thin layer of ultra-violet light at the surface where the cathode rays strike the substance. Schmidt finds that the cathode rays are strongly reducing in their action, and work not by the production of ultra-violet light, but in such a way that the negatively charged electrons reduce the positive valency charges of the metal. The last can then no longer hold back the whole acid radical—it weakens it, in case it is unstable. With salts of which the acid radicals are not unstable there enters under the influence of the cathode rays a dissociation into ions; after a longer working eventually a small reduction.—*Ann. der Physik*, No. 2, 1902, pp. 321–332. J. T.

10. *Effects of Currents of High Frequency upon the Human Body.*—It is often stated that high-frequency currents can be received with comparative safety. H. ANDRIESSEN points out that the strength of current is not considered in this general

statement and finds that the human body cannot bear any greater currents at high frequency than at low frequency.—*Ann. der Physik*, No. 2, 1902, pp. 369–380. J. T.

11. *Distribution of Electric Current on Electrodes in rarefied Media.*—It is noticed that luminous areas appear on the metallic terminals of Geissler tubes which are dependent on the electromotive force employed. A. WEHNELT has studied the connection between the distribution of these areas and the current developed in the tubes, and arrives at the conclusions that when the luminosity does not cover the entire terminal, the current flows only through the part covered by the luminosity; the source of the cathode stream is coincident with the spot of light on the cathode. He investigated the relations between the areas of luminosity in different forms of electrodes and found that the stream density is the same in every case between the limiting surface of the luminosity and the dark cathode space.—*Ann. der Physik*, No. 2, 1902, pp. 237–255. J. T.

12. *The Stratifications of Hydrogen.*—Sir WILLIAM CROOKES gives the details of his attempt to prepare pure hydrogen. He gives his reasons for believing that the blue components of the blue and pink strata in the stratifications produced by the discharge of electricity through rarefied hydrogen are due to a trace of mercury. Occasionally, when no mercury vapor was present a blue tint was observed which was traced to the phosphorus pentoxide tubes. The paper concludes with theoretical conclusions in regard to the causes of stratification based on the electron theory.—*Nature*, Feb. 20, 1902. J. T.

13. *Magnetic Declination Chart for the United States in 1902.*—The U. S. Coast and Geodetic Survey, O. H. Tittmann, Superintendent, has recently issued a chart of the United States, giving the curves of equal magnetic declination and also those of equal annual change for January 1st, 1902. The second series of curves, which has not always been plotted out as here, adds much to the interest of the chart.

14. *Die Fortschritte der Physik im Jahre 1902. Halbmonatliches Litteratur-verzeichniss;* redigirt von KARL SCHEEL (reine Physik) und RICHD. ASSMANN (kosmische Physik). Braunschweig, 1902 (Fr. Vieweg und Sohn).—The Deutsche Physikalische Gesellschaft has undertaken the publication of a semi-monthly catalogue giving the titles of all papers published in the various departments of physics. These are given under the author's name with title in the original language and are classified into groups according to subject. Five numbers of the series (pp. 1–115) have been received, the last bearing the date of March 15.

This new publication, which is supplementary to the well-known "Fortschritte der Physik," now in its fifty-seventh volume, will be of great value to all active physicists and should be well supported.

II. Geology.

1. *United States Geological Survey.*—The following publications have recently been issued.

Monograph XL.—Adephagous and Clavicorn Coleoptera from the Tertiary Deposits at Florissant, Colorado, with Descriptions of a few other Forms and a Systematic List of the non-Rhynchophorous Tertiary Coleoptera of North America; by Samuel Hubbard Scudder.

Bulletins. No. 177.—Catalogue and Index of Publications of the United States Geol. Survey, 1880–1901; by Philip Creveling Warman. Pp. 858.

No. 178.—The El Paso Tin Deposits; by Walter Harvey Weed. Pp. 15.—Three veins have been discovered ten miles north of El Paso, Texas, containing cassiterite with wolframite in a gangue of quartz. The ores are the result of deep-seated agencies and "it is believed that further exploration will develop well-defined tin veins."

No. 180.—The occurrence and distribution of Corundum in the United States; by Joseph Hyde Pratt. Pp. 93.

No. 181.—Results of Primary Triangulation and Primary Traverse, Fiscal Year 1900–1901; by H. M. Wilson, J. H. Renshawe, E. M. Douglas and R. U. Goode. Pp. 228.

No. 183.—A Gazetteer of Porto Rico; by Henry Gannett. Pp. 51. This bulletin contains a summary of the recent Porto Rican census and the official spelling of geographic names pertaining to the island.

No. 184.—Oil and Gas Fields of the Western Interior and Northern Texas Coal Measures and of the Upper Cretaceous and Tertiary of the Western Gulf Coast; by George I. Adams. Pp. 62, with 10 plates and 4 cuts.

No. 185.—Results of Spirit Leveling, Fiscal Year 1900–'01; by H. M. Wilson, J. H. Renshawe, E. M. Douglas and R. U. Goode. Pp. 207.

No. 186.—On Pyrite and Marcasite; by H. N. Stokes. Pp. 48. The results of this investigation are given on pp. 414–420 of vol. xii of this Journal, Dec. 1901.

No. 187.—Geographic Dictionary of Alaska; by Marcus Baker. Pp. 11–446. This bulletin is the result of some ten years work on the part of the Board on Geographic Names. A descriptive list of authorities is given and in the main body of the work the origin, history, modes of spelling and application of each name and in the case of Indian, Eskimo and foreign names their meaning also is given. The approved forms of spelling are shown in bold-faced type.

The Geologic Branch of the Survey has been reorganized by the appointment of C. Willard Hayes as Geologist in charge of Geology. This arrangement will relieve the Director of executive details and will make it possible for Bailey Willis, who since

1897 has performed the administrative work of Geology, to give more attention to the division of Areal and Stratigraphic Geology of which he has charge.

2. *The Fauna and Geography of the Maldive and Laccadive Archipelagoes;* edited by J. STANLEY GARDINER. Vol. i, part i, with plates i–v, and text illustrations 1–23, pp. 1–118. Cambridge, 1901.—This work, of which the first part is now published, gives an account of the investigations carried on by an expedition, headed by Mr. Gardiner, in 1899 and 1900. The special region studied was that of the Maldive Archipelago of Coral Islands, but a careful study was also made of the atoll of Minikoi, which forms the southernmost of the Laccadives. These two Archipelagoes lie to the south-southwest of the Peninsula of British India, although separated from it by a depth of 1,000 to 1,500 fathoms. The India Peninsula itself has practically no coral reefs, though the southern part towards Ceylon partakes of the same formation as the northern portion of that island. The part of the work now published contains an account of the atoll of Minikoi, from which some quotations are given below, and besides papers on the Hymenoptera by P. Cameron, on the Land Crustaceans by L. Borradaile, and the Nemerteans by R. C. Punnett.

"The surface of Minikoi island is sharply divided into two areas, an outer, covered on the surface with large loose coral or rock masses, and an inner with sand." In the outer area, "*Madrepora, Pocillopora* and other branching corals are found with their stems still unbroken while massive species have their calicles and septa even yet entire, *absolutely negativing the possibility of a beach origin for the rocky area.*" At the base of the outer beach is a conglomerate which seems "to have constituted part of the original reef (which by subsequent growth fashioned the atoll of Minikoi)" and which "may be considered to prove conclusively an elevation of the atoll," "of at least 24 feet." An examination of all the facts indicate "that the atoll existed as such when the change of level took place," that it has "been stationary for a considerable period of time." "Supposing the land in the present atoll to be entirely swept away, the condition at the present day cannot be far different from that of the atoll before the change of level, allowing for its then smaller size."

3. *The Formation of the Maldives.*—Mr. J. STANLEY GARDINER closes an interesting article on the results of his expedition to the Maldive archipelago (Geographical Journal, March, 1902, pp. 277–296) with the following remarks on the origin of the coral atolls:* "It [the expedition] has shown that the banks of the Maldives arise on a common plateau at a depth of about 190 fathoms. The land has been undoubtedly, by some means or other, raised above the sea, and is now everywhere on the larger banks being washed away. The atoll-reefs are growing out-

* See the preceding notice, also the paper by Professor Agassiz, pp. 297–308, of this number.

wards on all sides, while their lagoons are increasing in area, and probably also in depth. The atolls owe their existence to the fusion of reefs lying on the circumferences of banks, together with the washing away of the reefs in the interiors of the same banks as their circumscribing reefs became more perfect. In general, the results of the expedition are in striking agreement with the conclusions drawn by Sir John Murray as to the formation of atoll reefs ; but I should hesitate to apply these views to all coral-reef areas in the present state of our knowledge, to the exclusion of the subsidence or any other hypothesis."

4. *Om de senglaciale og postglaciale Nivåforandringer i Kristianiafeltet (Molluskfaunan).* Norges geologiske undersögelse, No. 31, pp. xii, 1–731, pls. i–xix, 1900–1901 ; by W. C. BRÖGGER. —The terminal moraines on both sides of the Christiania Fiord were considered by De Geer as indicating the lower limit of the last great ice sheet, but the results of the investigations by Professor Brögger in this work show that the land ice extended to the extreme boundary of the land mass in Southern Norway, and even beyond this limit.

Many new occurrences of the late and post-glacial deposits are recorded and accompanied by lists and illustrations of the contained faunas. On the basis of their molluscan fossils, these deposits are classified into a number of divisions, indicating changes in level and climate.

There was first a period of subsidence of the land after the morainic period (ra-time), which is divisible into six stages. This was followed by a period of reëlevation divided into seven stages and reaching down to the recent period. The climate during the latter part of the post-glacial uplift was somewhat warmer than at present. Brögger agrees with Ekholm in his time-estimate of 9000 years since the formation of the Kitchen-middens of Denmark, or the beginning of the Littorina Sea in the Baltic area.

The succession of faunas and deposits is treated in great detail, and the whole work is an admirable example of exact methods of geological and faunal correlation. C. E. R.

5. *The Berkeley Hills—A Detail of Coast Range Geology ;* by A. C. LAWSON and CHAS. PALACHE. Bull. Dept. Geol. Univ. Cal., vol. ii, pp. 349–450, pls. 10–17, map. Berkeley, Cal., 1902.— The area described in this memoir is about six square miles in extent, lying immediately northeast of the town of Berkeley and long used as a subject of field drill for students in geology. The subject matter is, therefore, brought out in a somewhat detailed and popular manner for local usage and benefit. The geology comprises the description of a series of Cretaceous and Tertiary beds, folded and faulted and mingled with intrusive and extrusive igneous materials. These volcanic accumulations are of different periods and described under the heading of the sedimentary series they accompanied. They consist of rhyolites, andesites, laterites and basalts and in the lowest members of serpentines. The petrography of these rocks, accompanied by analyses, is given

by Palache, and the interesting fact is brought out that in five recurrent periods of eruption the sequence has invariably been, andesite, basalt, rhyolite in each period. This is harmonious in principle, if not in exact detail, with the general laws regarding the succession of eruptive magmas as observed in other areas.

L. V. P.

6. *Gesteine der Ecuatorianischen Ost-Cordillere, Der-Cotopaxi und die umgebenden Vulkanberge;* von A. YOUNG. (Reiss & Stübel: Reisen in Süd Amerika. Hochgebirge der Repub. Ecuador II Petro. Untersuch. 2 Ost. Cord. Berlin, 1902, 4°, pp. 275, 4 pl.).—This work, offered as an inaugural dissertation for the doctor's degree, is a further continuation of the series of investigations being carried on in the mineralogical-petrographical department of the University of Berlin, under the supervision of Prof. Klein, upon the material brought back by Reiss and Stübel.

The first half of the work contains a detailed account of the topography and physiography of the well known volcano of Cotopaxi. Its history, its varied outbreaks, its geological relations, the effect of erosion and its glaciers and glaciation are fully treated. This part is by W. REISS.

The petrographical portion, by Young, consists of a detailed and careful study of the various lavas, rock types, which are all comprised under the heads of dacites, andesites of various kinds and basalts. The descriptions are accompanied by a number of analyses. While the rocks described are of well known types, the work is, on the whole, a decided addition to our knowledge of the Andean rocks.

L. V. P.

7. *Der grosse Staubfall vom 9. bis 12. März, 1901, in Nordafrik, Süd- und Mitteleuropa;* von G. HELLMANN und W. MEINARDUS. Abhandl. k. pr. Meteorol. Instituts., Bd. II, No. 1. Berlin, 1901.—Some years ago, Ehrenberg maintained that the dust falls of Europe were derived from South America. This idea never gained general acceptance, and it is now completely disproved for the remarkable dustfall of March 9–12, 1901, concerning which the above cited memoir presents abundant and convincing data. Dust storms were observed in the Algerian Sahara during the days immediately preceding the dustfall in Europe, and a stormy sirocco prevailed over the Mediterranean; North of the Alps, direct observation at mountain observatories and the computed gradients at a level of 2500 met. indicated the prevalence of a southerly current moving at a rate of 70 kilom. an hour; and this rate agrees with that of the extension of the area over which dust spread. In the south, the dust fell from the dry sirocco; in the north it came down with rain and snow. The composition of the dust, prevailingly quartz, was such as the Sahara might furnish. Larger and heavier grains were collected in the south than in the north. In north Germany the quartz grains averaged 1 : 3,200,000,000 gram in weight. The total quantity of dust imported on this occasion from the Sahara is estimated at about 2,000,000 tons.

W. M. D.

8. *Ricerche Petrografiche e Geologiche sulla Valsesia di* E. ARTINI e G. MELZI. Mem. del. Istit. Lomb. di Sci. e Lett., class. di Sci. mat. e nat., vol. xviii, pp. 219–392, 4°. Milan, 1900.—The region described in this memoir lies in the Alpine portion of northern Italy, southeast from Monte Rosa and comprises mainly the basin of the Sesia and its tributaries. It consists chiefly of highly crystalline rocks, of gneisses of several types, and mica schist with lenses of crystalline limestone, lime schists and serpentine associated with large masses of granite and gabbros passing into diorites and peridotites. These rocks have been carefully studied in the field and the results attained are given with the aid of a geological map and cross sections. The petrographic study of the rocks collected is presented in considerable detail accompanied by twenty beautiful large plates reproducing micro-photographs of the various rock types. The work, besides its local value, is a considerable addition to our knowledge of the crystalline rocks of the Alpine region. L. V. P.

9. *Influence of Country Rock on Mineral Veins;* by WALTER HARVEY WEED. Transactions Amer. Inst. Min. Engin., Mexican meeting, November, 1901.—There is discussed in this paper, first, the influence of the country rock on the shape and size of the rock fissures in which subsequently mineral material has been deposited; second, the influence which the chemical nature of the rocks may have on this mineral content. From his discussion Mr. Weed concludes that the nature of the country rock through which a vein fissure runs has determined in great part the nature of the fissure, such as its course, width, etc.; that the character of the mineral contents of a vein, which is formed wholly by the filling of an open fissure, cannot have been determined by the character of the wall rock, but that, in the case where metasomatic replacement of the fissure walls has occurred, the nature of those walls has influenced the character of the minerals deposited; lastly, that as the metasomatic processes must vary with the variation of the mineral solutions, no invariable general relation can be established between certain rock types and rich ore deposits. W. E. F.

10. *Additional notes on the Cambrian of Cape Breton, with descriptions of new species;* by G. F. MATTHEW, LL.D., F.R.S.C. From Bulletin of Natural History Society of New Brunswick, Canada, No. xx, vol. iv, pt. v, pp. 377–425, with 5 plts.—This is a continuation of Dr. Matthew's studies on the Cambrian Faunas of Cape Breton. The present article gives (1st) new species of the Etcheminian or Basal Cambrian and (2d) a description of the Tremadoc Fauna which has been found in one of the Cambrian valleys.

The following new species and mutations are described in this paper and figured in five plates at the end. *Acrothyra*, 2 species (one already published) and 6 mutations. *Acrotreta*, 1 species, 1 mutation, and a species referred to an European form. *Acrothele*, 3 species (one already published) and 1 mutation.

11. *Analysis of Mount Vernon Loess*; communicated by NICHOLAS KNIGHT.—Loess occurs to a considerable depth on the hills in the vicinity of Mount Vernon, Iowa. On the somewhat elevated ridge on which Cornell College is located, the formation extends to a depth of 40 feet, diminishing from the summit. In general, it overlies the Kansan and Paha drifts, but it is usually absent over the Iowan. A brickyard is located in the Mount Vernon loess from which a good quality of brick is obtained. The specimen chosen for analysis was taken from the brickyard, eight feet below the surface of the earth. The analysis was made by Frank Hann in the chemical laboratory of Cornell College, under the direction of Dr. N. Knight. The following results were obtained:

SiO_2	CO_2	Fe_2O_3	Al_2O_3	MnO_2	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	FeO	H_2O	
70·86	4·70	2·97	8·91	0·28	4·13	3·12	1·18	1·69	0·59	0·40	0·10	1·10	=99·98

III. BOTANY AND ZOOLOGY.

1. *Horticultural Experiments and Botanical Investigations at the Harvard Station in Cuba.*—Through the kindness of Mr. Edwin F. Atkins, the Botanic Garden at Cambridge has been able to undertake a series of interesting studies relative to certain features of the vegetation of Cuba. Mr. Atkins has placed at the disposition of the Botanic Garden a sufficient lot of land for experimental purposes and has supplied the funds for current expenses. He has also provided adequate local labor.

The first series of experiments, covering a period of about four months, was designed to test the possibility of repeating, in the climate of Cuba, the well-known Javan studies in the pollination of the sugar-cane. The work was entrusted to the experienced hybridizer, Mr. Robert M. Grey. At the date of writing, his experiments appear to be successful in a high degree, although the present season has been unfavorable on account of prolonged drought. Mr. Grey and the assistant, Mr. Bohnhof, have now brought under cultivation rather more than one hundred different sorts of tropical and subtropical plants, and they are prosecuting the task of improvement in a systematic manner.

Mr. Ames, Assistant Director of the Harvard Garden, has lately visited the Experiment Station, and expresses himself in general as well pleased with the outlook.

Should the Experiment Station develop along the lines now marked out, it is hoped that arrangements can be made by which the establishment can freely offer its hospitality to students who may wish to get a glimpse of the interesting vegetation of the southern part of Cuba.

Colonia Limones, where the Station is located, lies rather less than twenty miles from Cienfuegos. The soil at the station is very well adapted to plants which prefer a more or less dry season in which to ripen the crop early. At a comparatively

short distance from the present Station there is another Colonia which may later be employed for the plants which demand much more moisture. Mr. Grey has collected in the vicinity certain products from the remarkable "escapes" from former cultivation. In some instances, the coffee and self-sown cotton go back to a period coincident with the beginning of the disturbances in this part of the island. In many cases, these products are of fair, in others of excellent, quality. If one can judge from the character of these products of plants which have become practically wild through abandonment, there is great encouragement to resume cultivation at the earliest practicable moment. By selection, crossing, and hybridizing, and by judicious adaptation of plants to special soils, the Station undertakes, in a modest way, to lend a hand towards the restoration of prosperity to some of the districts which have felt the effects of neglect of agriculture through civil war. G. L. G.

2. *Professor van Tieghem's Classification of Plants.* Ann. des Sc. nat., xiv, No. 4, 5, 6.—We have had more than one occasion to call attention to the interesting suggestions made by Professor vanTieghem, in regard to defects in the accepted classifications of plants. In the present work, the author offers still further suggestions, and constructs a system which he now offers as a basis for discussion.

He takes as his basis the embryo, in its widest sense.

It is well known to our readers that the author has devoted many years of assiduous study to the investigation of the ovule. His results led him two years ago to extend the research through the Cryptogamia, and see to what extent the fertilized germ could be utilized as a safe basis of classification throughout. Although the present communication covers almost 200 pages, it is justly regarded by the author as merely a tentative "essay," in the etymological sense of the word.

It has been necessary for the author to substitute for the terms generally accepted, a set of new terms, some of which do not easily pass over from their French form into terms which could be employed in English or, in short, in any other language, except Italian. This is particularly unfortunate, for the author has selected a good Greek substratum for his new words. But we have found it difficult to turn *Tomiées*, *Adiodées*, *Macrodiodange*, etc., into forms which accord with our English usage.

Leaving this difficulty out of account, we may say that the whole paper is filled full of most interesting subjects for the systematist, and shows clearly that the last word has not yet, by any means, been said in regard to a classification of plants based on their development.

Moreover, the frank admission of the author that the suggested system has many lacunæ, large and small, some of which he points out, makes the work attractive from its transparent honesty. Commending the communication to our readers as one of the most important contributions for many years, embodying,

as it does, the results brought out in his previous "essays" *in* this subject, we may say that Professor vanTieghem appears to us to have indicated some of the main lines upon which the system of the future will be founded. As Sir Joseph Hooker said, in substance, long ago, the Natural System which is to express the relationships of plants faithfully, must wait until much more has become known in regard to the structure, development, and behavior of all plants. And, even then, the Natural System will present the conditions only for the time, since changes in structure, mode of development, and behavior are constantly taking place. G. L. G.

3. *The Botanisches Centralblatt*, under its new management, preserves the best traditions of its former excellence and has, at the same time, considerably increased its range. Dr. Lotsy, of Leyden, the editor in chief, is fortunate in having the services of a goodly number of careful writers of abstracts, and he is now confronted with the serious task of judicious sifting what they report. Many persons are watching with interest the manner in which he will reduce to their proper places the notes which possess no scientific importance, in order to make room for references to contributions having permanent value. Up to the present time this work of selection has been done in such a way as to promise well for the future. G. L. G.

4. *Additions to the Fauna of the Bermudas from the Yale Expedition of 1901, with Notes on Other Species;* by A. E. VERRILL. Trans. Connecticut Acad. Sci., xi, pp. 15–62, pl. i–ix, 1901.—In this important paper Professor Verrill records some of the results of his second expedition to Bermuda. A large number of species, including representatives of almost every group of invertebrates, as well as several fishes, reptiles and mammals, are here recorded which have not before been found on the islands. Many species of invertebrates, including especially the Tectibranchiate and Nudibranchiate Mollusks, Planarians, and Anthozoa, are described as new to science, and figured from drawings and photographs. W. R. C.

5. (1) *Variations and Nomenclature of Bermudian, West Indian, and Brazilian Reef Corals, with Notes on Various Indo-Pacific Corals.* Pp. 63–168, Oct. to Dec., 1901.

(2) *Comparisons of Bermudian, West Indian, and Brazilian Coral Faunæ;* by A. E. VERRILL. Trans. Connecticut Acad. Sci., xi, pp. 169–206, pl. x–xxxv, Dec. 1901.—Some of the results of Professor Verrill's studies on the reef corals carried on during the past forty years are included in these two articles, which together form a most important monograph on the subject.

A number of the names of genera have been changed in accordance with the rules of priority. One of the most important instances is the adoption of *Mœandra* (Oken, 1815) in place of *Mœandrina* (untenable for this group), and the union of *Diploria*, *Manicina*, *Cœloria*, and *Leptoria* with it.

Another instance is the uniting of *Mussa*, *Symphyllia*, *Iso-*

phyllia, and part of *Ulophyllia*, under *Mussa*, the earliest name. Another important change is the adoption of *Acropora* (Oken) in place of *Madrepora* (Linné), and the transfer of the latter to *Lophohelia* (E. and H.). All West Indian forms of *Acropora* are united under *A. muricata* (L.), but a large number of forms are admitted as named varieties, some of them newly described.

The extended and detailed character of the generic and specific descriptions, and the excellence of the illustrations will serve to determine beyond question the species and varieties referred to, and this is of especial importance in a group where distinguishing diagnoses are more than ordinarily difficult to establish. Habits, methods of growth, geographical distribution and appearance of the living coral are included in many instances. The Bermudian coral-fauna "must be regarded as a detached colony of the more hardy species which have migrated from the West Indies through the agency of the northward currents, by which their free-swimming larvæ have been carried," although certain very common West Indian species are absent while others of the same genera are present in abundance. The West Indian coral-fauna is directly related to that of Brazil, although very few species are strictly identical. It is, however, totally distinct from that of Panama and the Indo-Pacific region. A few species may be identical with forms from the eastern Atlantic. The few known Brazilian reef corals present remarkable archaic characters indicating an ancient fauna that has mostly disappeared.

Especially noteworthy are the twenty-six beautiful plates of photographic reproductions which illustrate both papers. These represent the new species and varieties, as well as typical specimens of the common species. Many of the type specimens of Dana, Verrill, and others, preserved in the Yale Museum, and also rare species from the American Museum, New York, are included.

A considerable number of East Indian and Pacific Ocean corals are also described and figured, including several new species.

W. R. C.

6. *Some Spiders and Mites from the Bermuda Islands;* by NATHAN BANKS. Trans. Conn. Acad., vol. xi, pp. 268–275, January, 1902.—This is a catalogue of the spiders collected by the Yale parties in 1898 and 1901 with their distribution, and with revised lists of the species previously recorded. The number of species collected in 1898 and 1901 was 28. The total number now known from the islands is 33. In this paper three new species are described.

7. *The Marine and Terrestrial Isopods of the Bermudas, with Descriptions of New Genera and Species;* by HARRIET RICHARDSON. Trans. Conn. Acad., xi, pp. 277–310, with 4 plates, January, 1902.—This memoir is a nearly complete monograph of the Isopods of the Bermudas, for it contains revised lists of the few species previously recorded, as well as descriptions and figures of numerous new species. Of the marine forms 13

species and two genera are new; of the terrestrial forms three are new species, one of which is the type of a new genus.

8. *British Museum Catalogues.*—The following are recent additions to the list of highly valuable and complete Catalogues issued by the British Museum of Natural History:

Catalogue of the Lepidoptera Phalænæ in the British Museum. Vol. iii, containing plates xxxvi–liv.

Catalogue of the Arctiadæ (Arctianæ) and Agaristidæ in the Collection of the British Museum; by Sir George F. Hampson. Pp. xix, 690.

A Hand-list of the Genera and Species of Birds (Nomenclator avium tum fossilium tum viventium); by R. Bowlder Sharpe, LL.D. Vol. iii. Pp. xii, 367.

Catalogue of the Collection of Birds' Eggs in the British Museum. Vol. i. Ratitæ, Carinatæ (Tinamiformes-Lariformes). By Eugene W. Oates. Pp. xxiii, 252; with 18 colored plates.

Catalogue of the Fossil Fishes in the British Museum. Part IV, containing the Actinopterygian Teleostomi of the Suborders Isospondyli (in part), Ostariophysi, Apodes, Percesoces, Hemibranchii, Acanthopterygii, and Anacanthini; by Arthur Smith Woodward. Pls. i–xix. Pp. xxxvii, 636.

9. *Bermuda and the Challenger Expedition;* by George Watson Cole, of Graham Court, New York City (privately printed). Pp. 1–16.—A bibliography giving a summary of the scientific results obtained at and near Bermuda by the Challenger Expedition of 1873.

IV. Miscellaneous Scientific Intelligence.

1. *Report of the Secretary of the Smithsonian Institution for the Year ending June 30, 1901.*—In his annual report, Professor Langley gives a summary of the work done by the Smithsonian Institution in its several fields of activity. In the appendixes to the general report are more detailed statements regarding the work of the National Museum, the Bureau of Ethnology, the National Zoological Park, the Astrophysical Observatory, etc. The field work in ethnology for the year included an expedition into Lower California, and two reports of peculiar interest—one the Codex Hopiensis, the other a paper on wild rice as an aboriginal food, are announced as ready for publication. The Astrophysical Observatory gives a preliminary statement regarding the eclipse expedition to Sumatra in May.

2. *An Important Discovery in Color Photography.* — At the meeting of the Connecticut Academy of Sciences, Wednesday, Feb. 12th, Prof. A. E. Verrill exhibited several remarkable photographs in natural colors, made direct from nature by a new autochromatic process, just invented by Mr. A. Hyatt Verrill of New Haven, after several years of experimenting. One of these photographs was of a bright-colored Bermuda crab, from life; another was a Bermuda landscape in which the beautiful tints of

the water, etc., are well brought out, as well as the soft creamy tints of the old stone residence at Walsingham, and the neutral gray of the rocks. Three other plates were copied from water-color drawings of groups of bright-colored Bermuda fishes, made from life by Mr. Verrill. The photographic reproductions of these drawings showed accurately all the tints and delicate shades of green, blue, pink, purple, yellow, and orange, beautifully blended. The colors in these pictures are peculiarly soft and natural, without the stiffness of the three-color process. The bright red colors appear to be the most difficult to render by this process, at present, but no doubt this will soon be remedied by further experiments now in progress. The photographs are on paper and are made by a purely photo-chemical process.

The process is certain to be of great value for photographing the colors of Natural History specimens and for reproducing paintings, but is not adapted for portrait work owing to the length of exposure required for the negatives. A. E. V.

3. *Lehrbuch der Meteorologie;* von Dr. JULIUS HANN, Professor an der Universität in Wien. Pp. 805, 111 figs., 8 pl., 15 maps. Leipzig, 1901 (Tauchnitz). — This admirable volume belongs to the highest class of scientific treatises. Its author is the leading meteorologist of the world, for many years director of the meteorological observatory at Vienna and for a still longer time editor of the Meteorologische Zeitschrift. He is the author of several smaller books, his Klimatologie being the chief of these, of many scientific memoirs, and of a host of shorter articles. His breadth of knowledge is shown by the completeness with which the pages of this new treatise make reference to original sources; his competence by the thoroughness with which every part of the subject is presented. Like Bartholomew's Atlas of Meteorology (the first published part of a projected physical atlas), which took highest rank on its appearance three years ago, Hann's Lehrbuch is indispensable to every well equipped scientific library and to every advanced worker in the science of the atmosphere. W. M. D.

4. *The American Philosophical Society.*—The general meeting of the Society will be held at Philadelphia, April 3d, 4th and 5th, 1902. The preliminary program gives a list of thirty papers covering a wide field of scientific subjects. See further, p. 400, Nov., 1901.

5. *A New Theory of Evolution;* by ALFRED WARD SMITH. The Abbey Press, New York. Pp. 1–256.—The author of this book believes that Economy, Efficiency and Harmony are primary and essential traits of universal progress and ought to be embodied in the theory and formula of evolution.

OBITUARY.

ALBERT RIPLEY LEEDS, for many years Professor of Chemistry at the Stevens Institute in Hoboken, N. J., died on March 13.